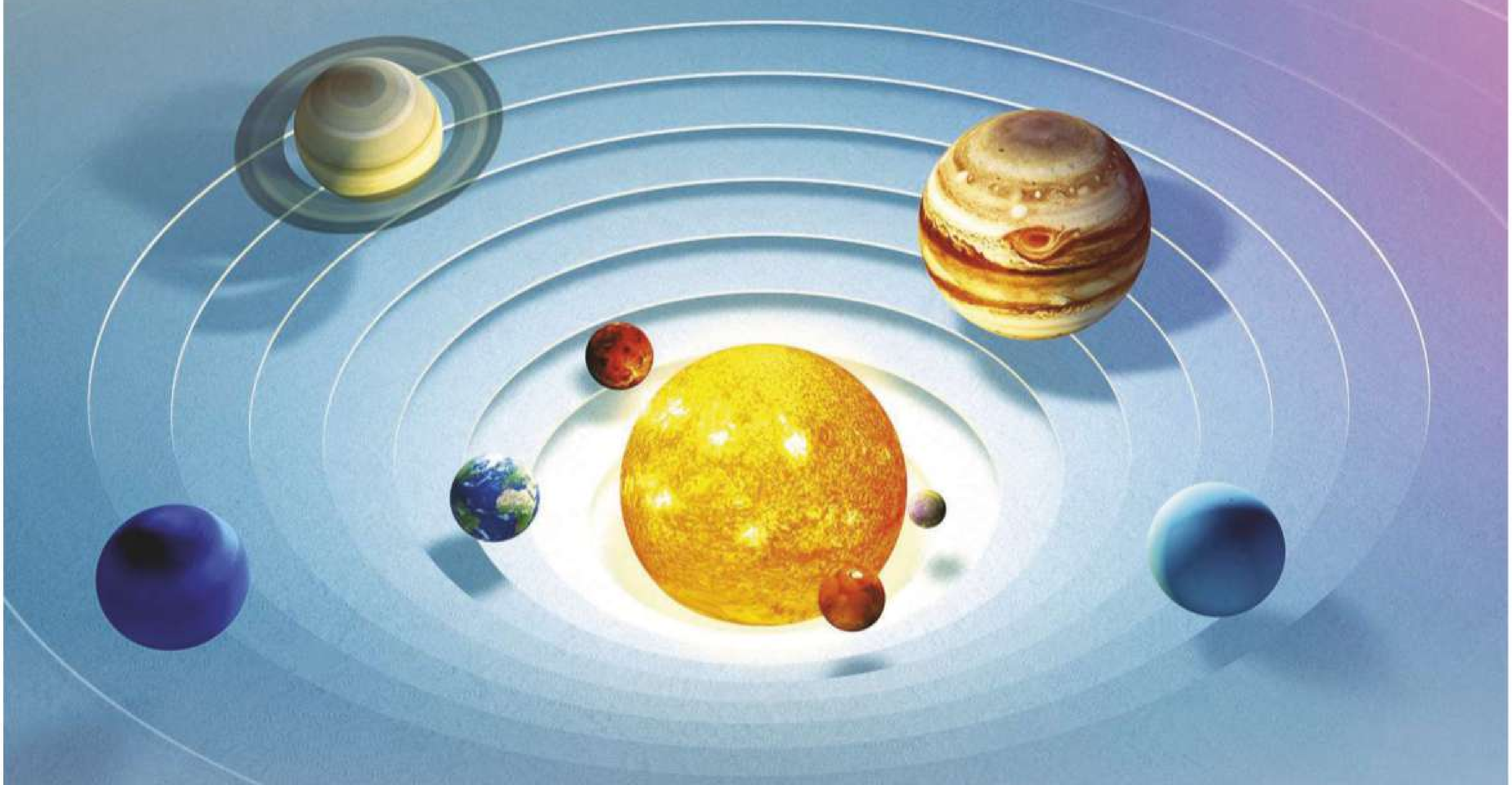
BBC

FOCUS MAGAZINE Collection
VOL.12

# THE ULTIMATE GUIDE TO THE SOLAR SYSTEM



How the Solar System began and how it will end

Mission into the Sun

The ice volcanoes of Saturn's moon Titan

The most mysterious objects in space

Back to the Moon

The new gold rush: mining Mercury

How humans will colonise Mars

Dodging an asteroid

Searching for life in Europa's oceans

# Neighbourhood watch

How well do you know your neighbours? They might only be next door, a little further down the street or just around the corner; you might see them passing by most days, you may even pop in for a cuppa and a chat now and then. But however familiar your neighbours may be, there's probably still a lot you don't know about them – enough that they can still surprise you from time to time.

The same can be said for our celestial neighbours spinning around the Solar System. We see the Sun, the biggest member of our neighbourhood, every day and a selection of the smaller ones (relatively speaking) every night. But the boundaries of our neighbourhood stretch so far that some members of it – most notably Neptune and, unless you've got very keen eyes, Uranus – lie beyond the range of our unaided sight.

Nevertheless, despite being spread over an unimaginably vast distance, we've gotten to know our cosmic community quite well. And doing so has resulted in some of humanity's greatest achievements: we've visited our closest neighbour, we've examined and explored our more distant ones with probes and rovers and, thanks to the two Voyager missions, we've even sent envoys into the unknown reaches beyond our neighbourhood.

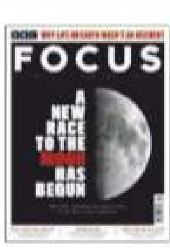
There's still a lot left for us to learn, though, which is why the Solar System and all the things floating around within it remain so endlessly fascinating. Because everything we discover about its planets, moons, comets, asteroids and star, only leaves us wanting to know more.

In this special issue, find out how the Solar System came to be (and how it will end), and learn about the latest audacious missions hoping to revolutionise our understanding of these alien worlds.

Enjoy this voyage of discovery!

**Daniel Bennett,** Editor







FRONT COVER: ANDY POTTS, THIS PAGE: SHUTTERSTOCK

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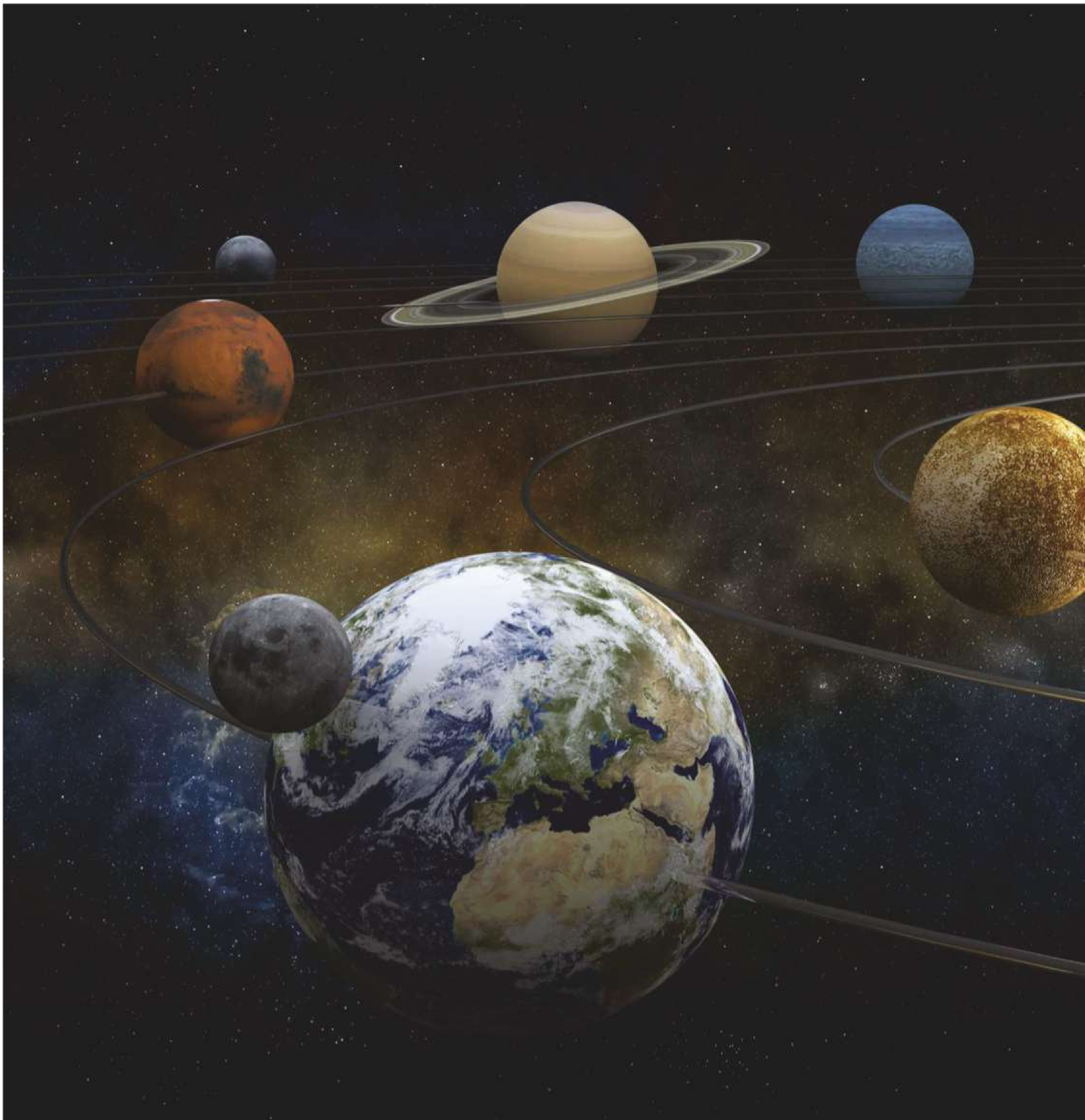

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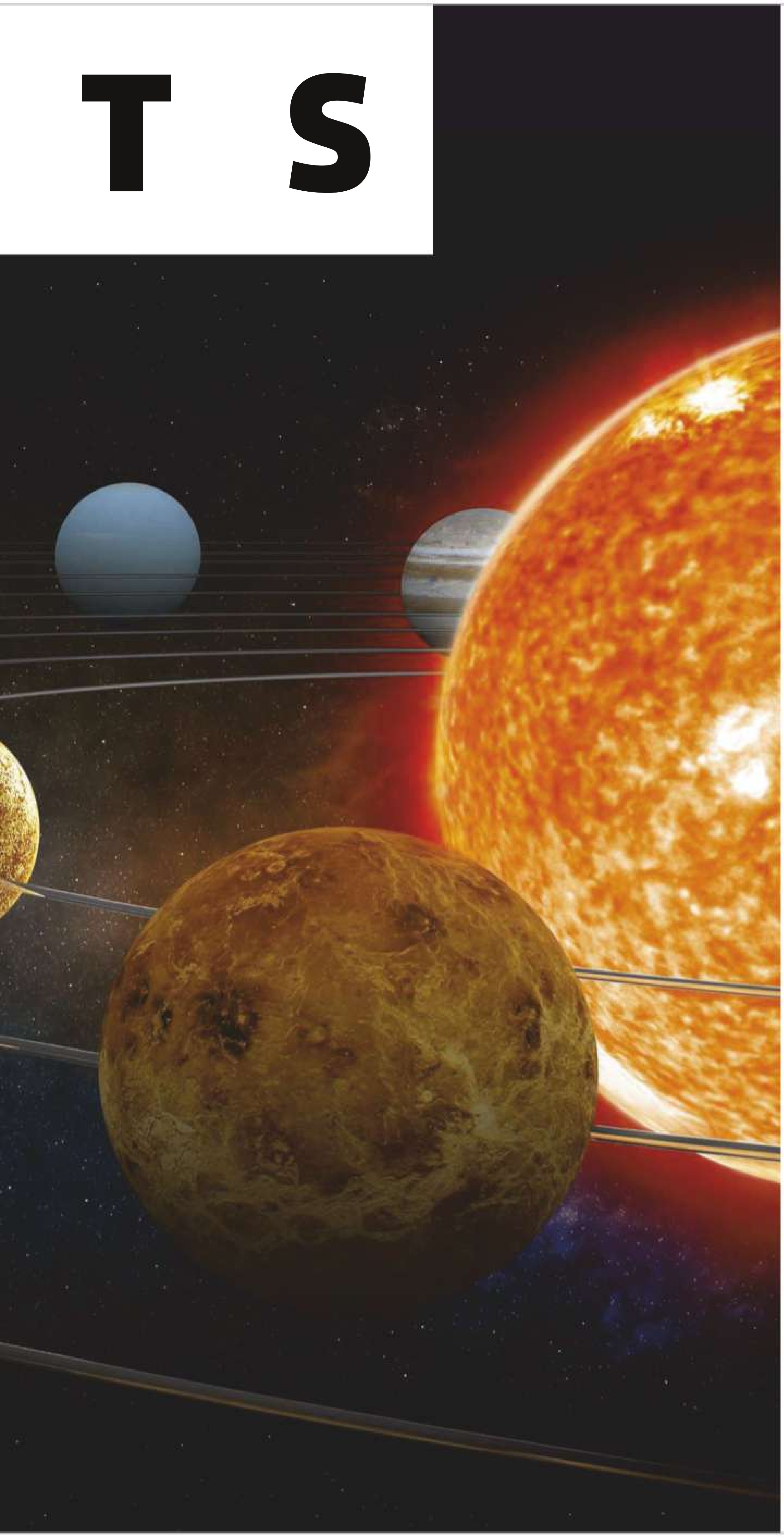


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# THE

# BIG BANG

Billions of years before our Solar System formed, the Universe was born…

WORDS: **STUART CLARK**

The year 2009 could go down in the astronomical textbooks as the one when a revolution in our understanding of the Universe began. The iconoclast at the centre of this upheaval is not a person but a machine: a space probe called Planck. Named after the great German physicist Max Planck, the spacecraft was launched by the European Space Agency (ESA) that year, tasked with detecting the 'blueprint' of the Universe – a snapshot of the seeds of the stars and galaxies that surround us today.

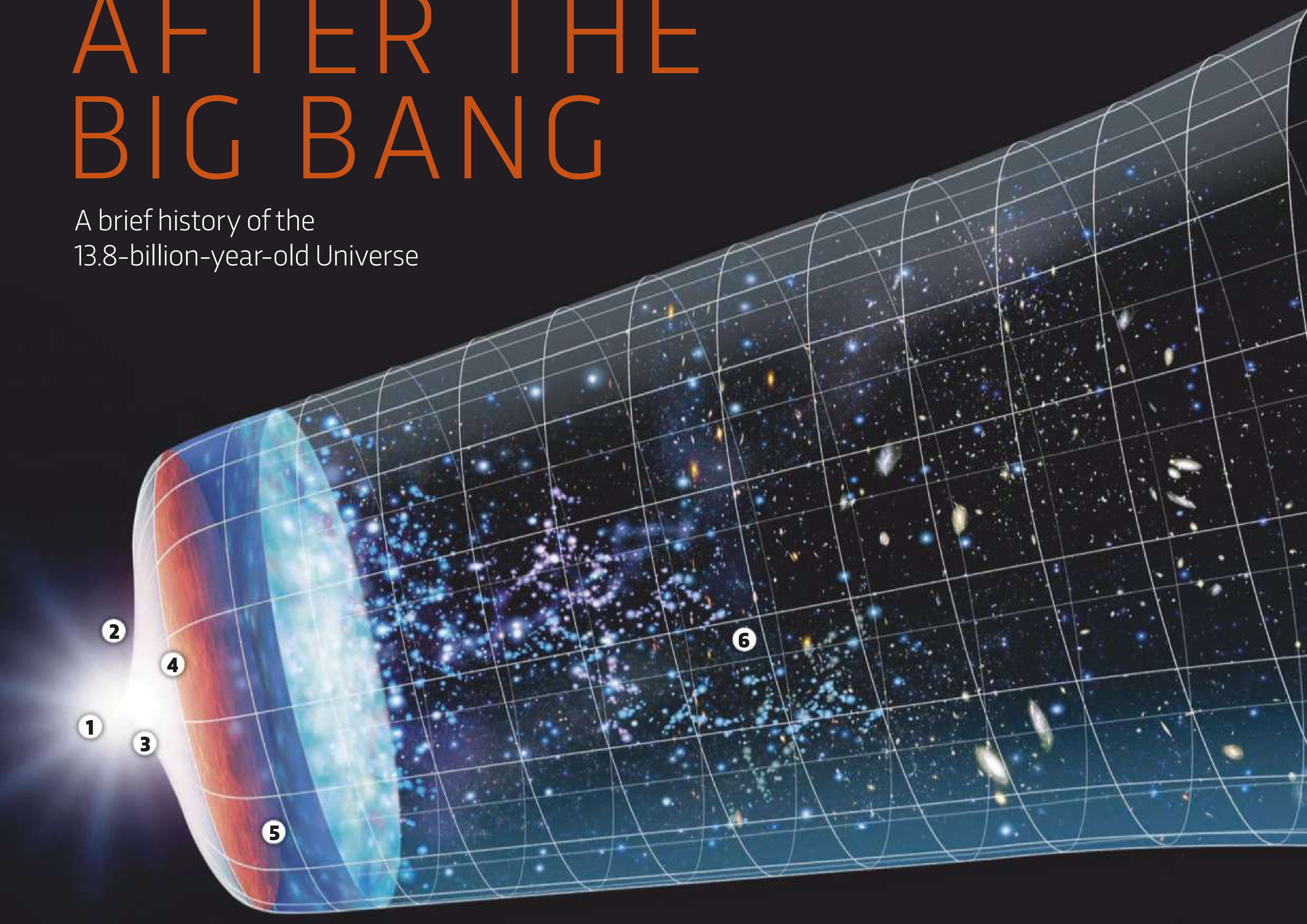
Since Albert Einstein published *Cosmological Considerations of the General Theory of Relativity* in 1917 cosmologists have been constructing mathematical theories that describe the story of the Universe from the earliest moments to the present day. But analysis of Planck's findings revealed a number of plot holes, or 'anomalies' as the scientists call them, that don't seem to fit the story. For one thing, data from Plank indicates that the Universe is older than expected, by about 50 million years. It also contains more of the mysterious dark matter and fewer atoms than previously thought. And while these may sound serious, in reality they are the least of a cosmologist's worries.

Much more troubling is the so-called 'cold spot' in the radiation from the early Universe that Planck has recorded – a region that looks significantly colder than current theories allow. Indeed, the temperature pattern across the whole Universe looks strangely lopsided.

Discoveries like these are shedding new light on the history of our Universe: the story of how we arrived at the cosmos we see today.

# AFTER THE BIG BANG

A brief history of the 13.8-billion-year-old Universe




## ❶ THE BIG BANG

At the moment of the Big Bang, 13.8 billion years ago, there were no stars or galaxies, just a hot, dense sea of particles and radiation. Straight after the Big Bang, space began to expand, spreading out the matter and energy.

## ❷ INFLATION

10-35 SECONDS POST-BIG BANG

In the blink of an eye, the Universe grew bigger by a factor of at least 1,060.

## ❸ PARTICLE CREATION

1 MINUTE POST-BIG BANG

At one minute old, the entire Universe resembled the interior of a star on a vast scale. Particles that would become the nuclei of all the atoms in the Universe were built in this cauldron. Mostly these were single protons that would become hydrogen, but around a quarter of the particles transformed into helium nuclei. Trace amounts of lithium and beryllium were also produced.

## ❹ THE DECOUPLING OF MATTER AND ENERGY

380,000 YEARS POST-BIG BANG

Until this moment it had been impossible for whole atoms to form; whenever a nucleus and an electron particle bonded together, the radiation smashed them apart again. Now, the continual expansion of space had weakened the radiation so much that it could no longer break apart the atoms. The afterglow of the radiation was captured by the Planck satellite.

## ❺ THE COSMIC DARK AGES

1 MILLION YEARS POST-BIG BANG

The expansion of space stretched the radiation into the infrared and then into the microwave sections of the electromagnetic spectrum. The Universe became dark. There were no stars, so no sources of light. Slowly, the sea of atoms began to fragment into clumps, pulling together to become the first celestial objects. The first stars were purely hydrogen and helium. They lived for just hundreds of thousands of years before destroying themselves and seeding the Universe with the heavier elements needed to form planets and life.

The Universe was born from a single point in time and space, a discovery made possible by identifying the radiation from the Big Bang itself

## ❻ THE FORMATION OF THE SOLAR SYSTEM

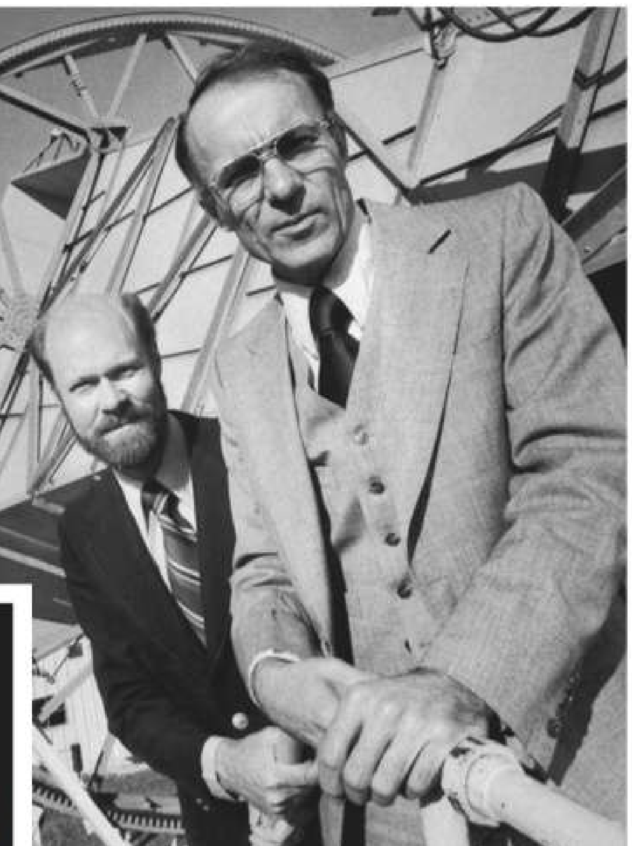
8.8 BILLION YEARS POST-BIG BANG

Before our star was born, another larger one had died in a supernova, filling the cloud with gas and dust. This debris was used to build the Solar System (see page 10).

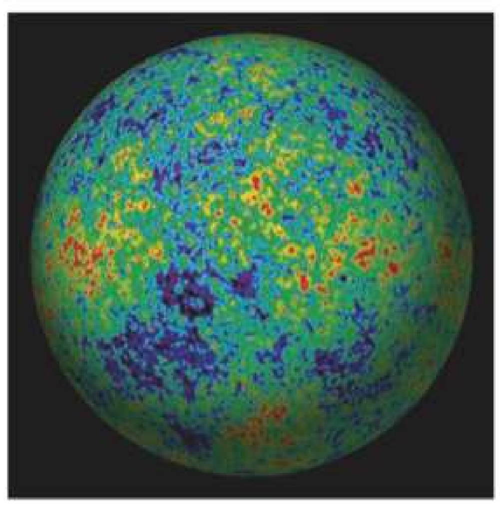


## THE KEY EXPERIMENT

| | |
|---|---|
| SCIENTISTS | Arno Penzias and Robert Wilson |
| DATE | 1964 |
| DISCOVERY | Heat signature of the Cosmic Microwave Background |



Robert Wilson (left) and Arno Penzias in front of the antenna that picked up the Cosmic Microwave Background



A map of the Cosmic Microwave Background – the afterglow radiation of the Big Bang

While working at the Bell Labs in New Jersey, in the US, radio astronomers Arno Penzias and Robert Wilson discovered a weak hiss coming from all directions in space. Initially baffled by this strange radio noise, their revolutionary discovery earnt them a Nobel Prize in 1978.

Radio waves are a type of electromagnetic radiation. The nature of this type of radiation depends on the temperature of the radiating object. The amplifiers used in the receiver were cooled to 4.2 Kelvin (-268.9°C) using liquid helium and a 'cold load' used to calibrate the system.

By switching the antenna from observations of the cold load to observations of the sky, Penzias and Wilson could measure the apparent temperature of the Universe (expected to be 0 Kelvin), then subtract known factors, such as the interference from Earth's atmosphere.

But, in 1964, it soon became clear that the radiation coming from the antenna into the receiver was at least 2 Kelvin hotter than they could explain. The pair did everything they could to remove any sources of interference, including cleaning out the layer of droppings that had accumulated in the antenna horn from a pair of nesting pigeons. Nothing made much difference.

The mystery of the 'excess antenna temperature' continued to baffle them until they realised, with the help of Robert Dicke, James Peebles, Peter Roll and David Wilkinson at Princeton, that they were looking at the afterglow radiation of the Big Bang.

**Dr Stuart Clark** is an author, cosmology consultant for the European Space Agency and a Fellow of the Royal Astronomical Society.

# How the Solar System formed

From our prime position on the third rock from the Sun, we're finally understanding how our solar neighbourhood came to be

WORDS: **COLIN STUART**

The Solar System formed around 4.6 billion years ago. It started out as a huge cloud of dust and gas (hydrogen and helium), which collapsed and fused together until it formed the star that we now know as the Sun. The remaining debris gradually formed a protoplanetary disc – a huge, flat circle comprising hundreds of lumps of rock and ice known as planetesimals, which were the building blocks of the Solar System. After a few million years of crashing and melding together, these bodies began to resemble the planets as we know them today.

**HOW DO WE KNOW THIS?**

Asking questions about where we come from is one of the traits that marks us out as human. Yet this inquisitive streak hasn't always led us in the right direction. The story of our quest to discover how the Solar System formed is littered with false starts, and it's a story we're still refining today.

The world's greatest thinkers originally had the Earth at the centre of creation, with the Sun, Moon, planets and stars circling around us. It's an idea that lasted for more than 1,000 years, dating back to the days of Aristotle and Ancient Greece. It wasn't until the Polish astronomer and mathematician Nicolaus Copernicus challenged this idea in the 16th Century that the tide of

BBC TWO

Look out for the new series *The Planets* with Brian Cox. Check *Radio Times* for details.

GETTY IMAGES

opinion started to shift. Copernicus said that the planets – including Earth – orbit around the central Sun and he was so fearful of the inevitable backlash from religious quarters that he delayed publication of his work until after his death.

**GALILEO! GALILEO!**

It would take decades for experimental evidence to confirm that we do indeed live in a solar system. It was mostly the work of Italian astronomer Galileo Galilei in the early 1600s that cemented the idea. It wasn't all plain sailing, of course. Galileo famously had his own run-ins with the church, and he was only officially pardoned in 1992. But as far as the science was concerned, the clincher came when he observed Venus waxing and waning through phases, like the Moon. This isn't possible if both Venus and the Sun orbit the Earth; only if both planets circle a central source of illumination. So we took our place as just another member of the Sun's family of planets.

Attention naturally turned to how such a system could come about. In the 1630s, the French philosopher René Descartes was one of the first to speculate. His starting point was the idea that nothing in nature could ever be empty. So if a particle in space moved position, another must move to fill the gap, creating a series of vortices. Descartes believed that the planets formed when material caught in these swirling vortices somehow condensed. It would take Sir Isaac Newton and his famous work on gravity to establish why the planets orbit the Sun. But that still didn't explain where the Sun and its planets came from.

It would take Sir Isaac Newton and his famous work on gravity to establish why the planets orbit the Sun

By the mid-1700s, French mathematician Georges-Louis Leclerc was suggesting that the planets formed when a comet struck the Sun, sending vast amounts of material surging outwards. Over time, he said, gravity collected this material together to form orbiting worlds. By the end of the century, Leclerc's compatriot Pierre-Simon Laplace had shown this to be impossible – any ejected material would have been pulled back in by the Sun's gravity.

Laplace then started to formulate an alternative explanation. The invention of the telescope had allowed astronomers to discover a series of fuzzy blobs scattered around the night sky. They called them 'nebulae', Latin for clouds. Laplace suggested that the Sun had formed from such a cloud. As the cloud collapsed under gravity it spun faster and faster. According to Laplace, material would have been thrown off the Sun as its rotation quickened, creating a flat disc surrounding the star. The planets were then formed when gravity gathered this material together.

Yet by the turn of the 20th Century, Laplace's idea had all but been abandoned. The problem was that if his explanation was correct, the Sun should spin a lot more rapidly than it does, and the planets should revolve at a more sedate pace. Unable to reconcile this issue, astronomers such as Sir James Jeans turned to an alternative explanation. In 1917, Jeans proposed that another star buzzed past the Sun and, in the process, its strong gravity tore off a significant amount of stellar material. That, said Jeans, provided the building blocks necessary to form the planets. But his idea didn't last long. By 1929, it had been shown that such a close encounter was extremely unlikely due to the vastness of space. What's more, even if it did occur, the Sun would have reabsorbed much of the lost material.

With no clear frontrunner, new theories continued to emerge as the decades rolled on. In the 1940s, British astronomer Fred Hoyle proposed that the Sun once had a much

RIGHT: Galileo Galilei, as depicted in this painting by Felix Parra, explaining his astronomical theories to a friar at Padua University

BELOW: A young star is surrounded by a formation of dust and gas known as a 'protoplanetary disc', in which new planets are forming

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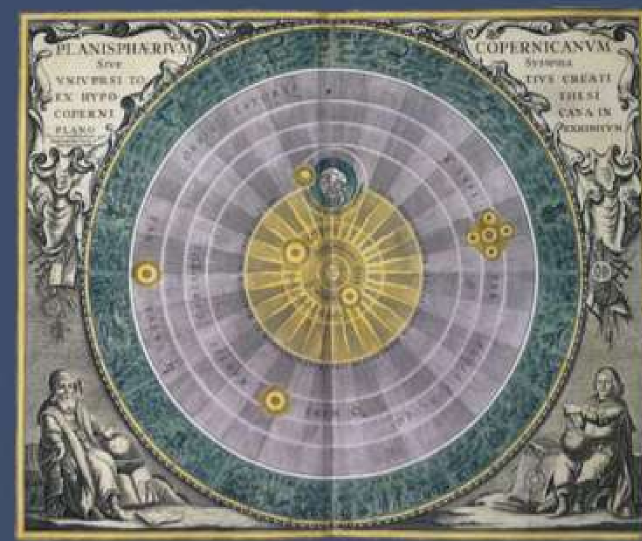
## THE KEY EXPERIMENT



A chart of the Solar System, as described by Nicolaus Copernicus, with the Sun at the centre

| | |
|---|---|
| SCIENTIST | **Nicolaus Copernicus** |
| DATE | **1543** |
| DISCOVERY | **Earth and the planets revolve around the Sun** |

It's hard to see how astronomers could have formed their current theories of how our Solar System came to be if we still thought everything orbited Earth. Copernicus's breakthrough – putting the Sun at the centre of things – is rightly lauded as one of the greatest scientific revolutions in history. And yet it wasn't inspired by astronomical observation, but by mathematical elegance.

The idea of geocentrism – that everything in the Universe orbited Earth – ran into a problem when observing the objects in the night sky. Some of the planets appeared to double back on themselves. To get around this the Ancient Greek polymath Ptolemy introduced 'epicycles', which saw the planets move in smaller circles, which in turn orbited around Earth.

But this was a big leap, introduced to force what we saw in the night sky to correspond with our belief that Earth was at the centre. Copernicus's genius was to realise that switching to having the Sun in the centre would do away with the need for epicycles. Under his heliocentric model, Mars appears to double back on itself because Earth overtakes the Red Planet as it orbits the Sun.

This monument to Copernicus stands in front of the Polish Academy of Sciences

larger companion star that had exploded as a supernova. Some of the resulting shrapnel was snared by the Sun's gravity, later coming together to form the planets. But that didn't hold water either, partly because it struggled to explain the low masses of Mercury and Mars.

> **But there is an alternative explanation: this fifth giant planet is still in our Solar System, waiting for us to find it**

It wasn't until the 1970s that things started to make more sense, when astronomers returned to Laplace's nebula theory. The main problem with this theory (that the observed rotation of the Sun was slower than expected) could be eliminated if drag caused by dust grains in the surrounding cloud had put the brakes on. This idea was buoyed in the 1980s when astronomers spotted dusty, flat discs of material around young stars, called protoplanetary discs, or 'proplyds'. They'd effectively caught planet formation in the act.

### ALIEN WORLDS

Observing other solar systems is now key to understanding how ours formed. But up until the mid-1990s no one had ever spotted a planet orbiting another star. That changed in 1992 with the discovery of a world orbiting a pulsar star. Since then, astronomers have uncovered almost 3,900 planets in other solar systems – so-called 'exoplanets'. But from the start it was clear that these alien neighbourhoods weren't all perfect mirror images of our own. For example, 51 Pegasi's planet, which has since been named Dimidium, takes just over four days to orbit 51 Pegasi. It's nearly eight times closer to its star than Mercury is to the Sun. What's more, Dimidium is around half the mass of Jupiter, making it a much bigger planet than Mercury.

With the hypothesis of planets forming from the debris of a newborn star, it is incredibly difficult to get such a giant world forming so close to its host. A more viable explanation is that the planet formed much further away and then migrated inwards over time. Here was compelling evidence that planetary orbits were not fixed, but could wander significantly. Bolstered by these discoveries, astronomers started to look at our Solar System with fresh eyes.

In 2005, a decade after the discovery of Dimidium, a group of astronomers proposed the Nice model (named after the city in France where it was formulated). The crux of this idea is that the giant planets of our Solar System – Jupiter, Saturn, Uranus and Neptune – started off much closer together. Over time, Jupiter moved inwards towards the Sun as the other three moved outwards. In some scenarios, Uranus and Neptune even swap places.

The movement of Jupiter towards the Sun would have scattered many smaller bodies, much like a dog running through a flock of pigeons. Many of these bodies would have ended up in the inner Solar System, creating a sharp peak in the number of meteors raining down on the rocky planets and their moons. And there is

ABOVE: Despite their distance from Earth, stars such as 51 Pegasi are helping us understand more about our own Solar System

RIGHT: An undiscovered planet could be lurking on the outskirts of our Solar System

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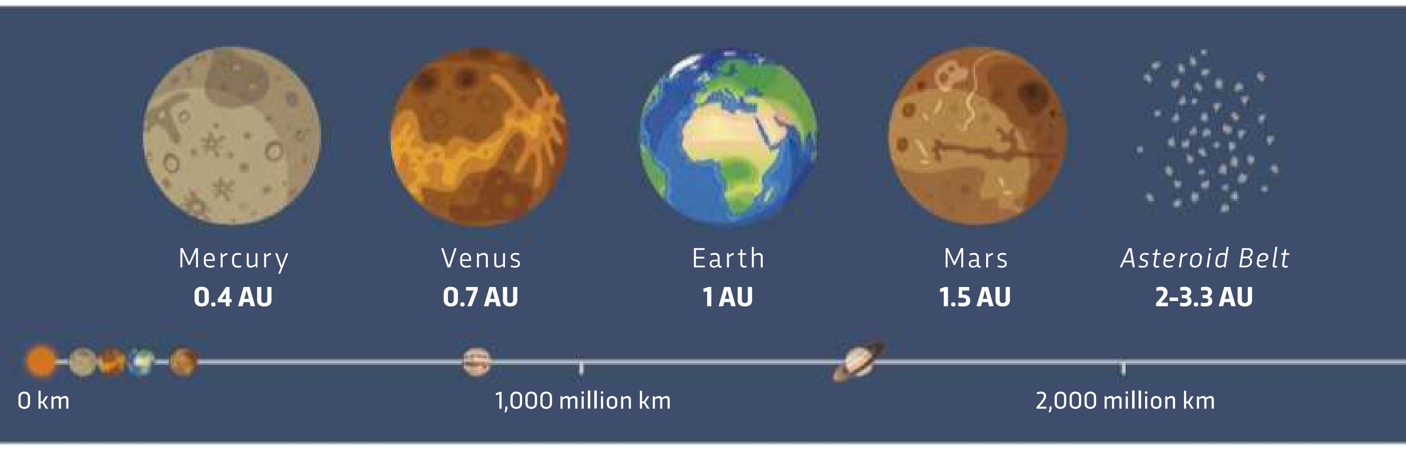
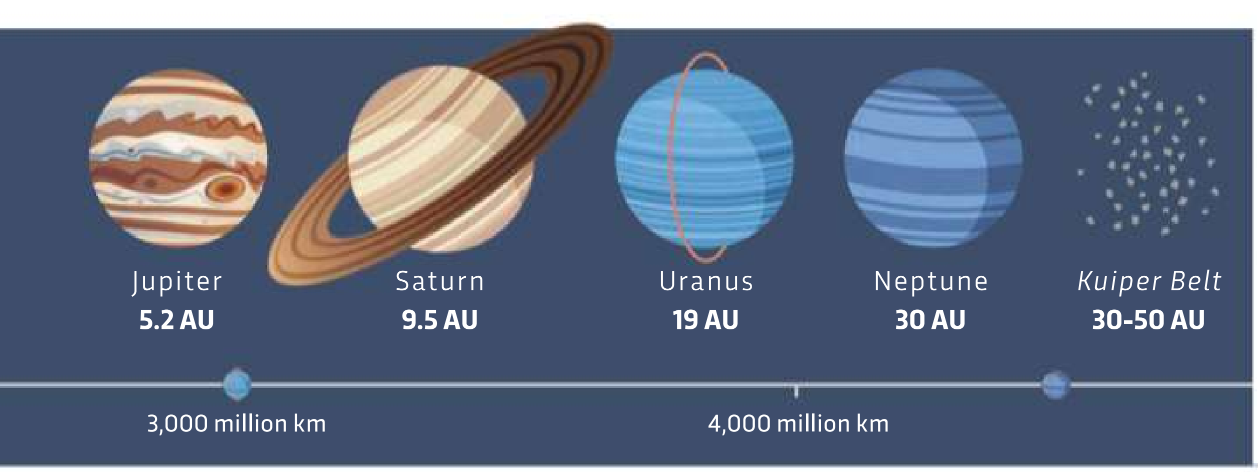
## DISTANCES FROM THE SUN

*The planets with their average distances from the Sun. 1 AU (Astronomical Unit) is the distance from the Earth to the Sun.*






evidence of a surge in impact activity on the Moon between 3.8 and 4.1 billion years ago. The outward movement of Neptune would also have sent smaller bodies running further from the Sun, helping to explain the Kuiper Belt and Scattered Disc – two reservoirs of smaller objects in the outer Solar System.

**A HIDDEN PLANET?**

Although it was a major step forward, the original Nice model was far from perfect. When using a computer simulation to recreate the gravitational interactions between the four giant planets, astronomers only ended up with a Solar System that resembled ours around three per cent of the time. But with one small modification they could boost this to 23 per cent. The modification? The addition of a fifth giant planet. Yet we've only ever seen four giant worlds. So if we're to take this explanation seriously we need to be able to say what happened to this other planet. It could have been ejected from the Solar System during the migration of its neighbours – an orphan planet left to wander the black void of space. Astronomers have already found some examples of these so-called 'rogue planets', so the idea is far from ludicrous.

There is, however, a more tantalising explanation: this fifth giant planet is still right here in our Solar System, waiting for us to find it. The buzz around this possible world, dubbed 'Planet X' or 'Planet Nine' has been one of the most exciting astronomical developments of recent years (see pages 79 and 94).

If such a planet does exist, the reason it's escaped our notice so far is its sheer distance from the Sun. Unless you know exactly where to look, it's easy to miss. A dedicated search is underway to hunt it down.

These latest astronomical adventures show us that the story of our Solar System's formation is still very much a work in progress. We may have come a long way since the days of Ancient Greece, but there are still many chapters left to write.

**Colin Stuart** (@skyponderer) is an astronomy writer and author of *The Geek Guide to Life*.

# WHERE ARE ALL THE **ACTIVE SPACECRAFT** IN OUR SOLAR SYSTEM?

Since Sputnik 1 was launched in 1957, humans have sent thousands of spacecraft into the cosmos. There are currently around 50 active* craft in our Solar System. Here's where they are and what research they are doing

*not including miniaturised, amateur or commercial craft

INFOGRAPHIC: TIDY DESIGNS

## SOLAR AND HELIOSPHERIC OBSERVATORY

The SOHO mission has revolutionised our understanding of the Sun. As well as providing valuable data on the Sun's magnetic activity, it has also inadvertently discovered 3,000 comets as they have buzzed past.

**STEREO A/B (SOLAR TERRESTRIAL RELATIONS OBSERVATORY)**
Building a 3D picture of storms erupting from the Sun. STEREO A is active, but contact was lost with STEREO B in 2014.

**SOHO (SOLAR AND HELIOSPHERIC OBSERVATORY)**
Studying the Sun's outer layers as well as the solar wind.

**DISTURBANCE REDUCTION SYSTEM (DRS)**
Part of a technology demonstration mission to track gravitational waves from space.

MERCURY

VENUS

**BEPICOLOMBO**
Launched in 2018, BepiColombo will arrive at Mercury in late 2025, and split into its two craft: the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO).

LAGRANGIAN POINT L1

**PARKER SOLAR PROBE**
Launched in 2018 and currently orbiting the Sun, it is gathering data on the solar wind.

**AKATSUKI**
Studying Venus's atmosphere and cloud decks. Entered orbit in December 2015.

**WIND**
Studying the solar wind. Has enough fuel to last for around 50 years.

**SPITZER SPACE TELESCOPE**
Taking infrared images of galaxies and nebulae. Most instruments have stopped working.

**ACE (ADVANCED COMPOSITION EXPLORER)**
Studying the Sun. Has enough fuel to last until 2024.

## SPITZER SPACE TELESCOPE

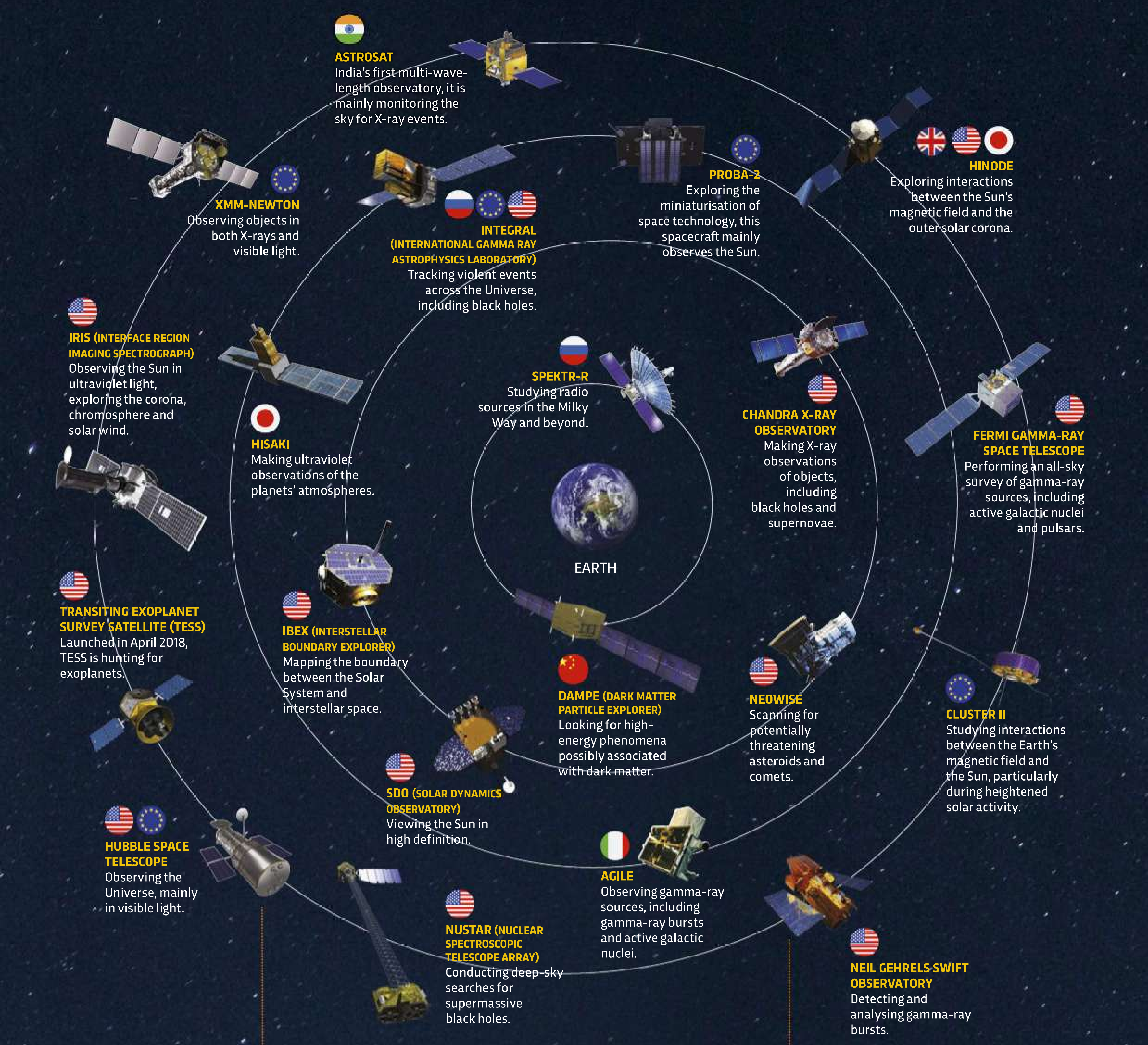
Spitzer, launched in 2003, is the fourth and last of NASA's Great Observatories, after Hubble, Compton (de-orbited in 2000) and Chandra. Spitzer observes infrared light and although the cryogen needed to cool its instruments ran out in 2009, the telescope is still observing asteroids, comets and exoplanets. In 2016, Spitzer was among the telescopes used to discover what might be seven potentially habitable planets in the nearby TRAPPIST-1 system.

## AKATSUKI

Many mysteries abound around Venus, and Akatsuki is the latest probe to take a closer look. It is searching for lightning in the Venusian atmosphere, studying the abundance and distribution of key gases and looking at how the planet's heat is distributed in the lower atmosphere. And that heat is significant – Venus is the hottest planet, even though it isn't closest to the Sun. Letters from a public competition went along for the ride on engraved plates.

**58 MILLION KM FROM SUN**

**108 MILLION KM FROM SUN**




## HUBBLE SPACE TELESCOPE

When the Hubble Space Telescope entered service in 1990, its images were found to be slightly blurry due to a flaw in its primary mirror. A service mission in 1993 fixed the issue and, since then, the telescope has been beaming back spectacular images of the cosmos. The telescope's contribution to astronomy has been far-reaching, enabling scientists to pin down the age of the Universe, discover dark energy, and witness the birth of planets and stars.

## NEIL GEHRELS SWIFT OBSERVATORY

The Neil Gehrels Swift Observatory is designed to study gamma-ray bursts – intense, short-lived flashes of the most energetic light in the Universe. It was launched in 2004 with an intended life of two years, but is still operating today. So far it has seen over 1,000 gamma-ray bursts. When a cosmic explosion triggers the telescope, a text message is sent to the on-call astronomer so that they can coordinate follow-up observations.

150 MILLION KM FROM SUN

## GAIA

Gaia is an astrometry telescope with the task of measuring the positions and distances of stars in our Milky Way galaxy with unprecedented precision. It was launched in 2013 and in April 2018 astronomers released the hotly anticipated second batch of data to the wider astronomical community. Gaia is also studying exoplanets and distant quasars, as well as asteroids in our own Solar System.

**GAIA**
Accurately cataloguing the positions of more than a billion stars.

**OPPORTUNITY**
Searching Mars for signs of water and amenable conditions for life. NASA is trying to reestablish contact with the rover after shutting it down to survive a dust storm.

**MRO (MARS RECONNAISSANCE ORBITER)**
Monitoring Martian climate and mapping future landing sites.

**ARTEMIS P1/P2**
Studying the interaction of the solar wind with the Moon.

**2001 MARS ODYSSEY**
Detecting evidence of past or present water on Mars.

**INSIGHT**
Touched down on Mars in November 2018. Its aim is to discover what lies beneath the Red Planet's surface.

MOON

**MAVEN (MARS ATMOSPHERE AND VOLATILE EVOLUTION MISSION)**
To discover how Mars lost its atmosphere and liquid water.

MARS

**MARS EXPRESS**
Performing comprehensive analysis of the Martian environment.

**LRO (LUNAR RECONNAISSANCE ORBITER)**
Making detailed lunar maps for future manned and robotic exploration.

**MARS ORBITER MISSION**
Demonstrating technology for future Indian Martian mission.

**CURIOSITY**
Assessing suitability of Martian environment for microbial life.

**EXOMARS TRACE GAS ORBITER**
Investigating the source of Martian methane.

**HAYABUSA2**
Japan's second asteroid survey and sample return mission. It arrived at asteroid 162173 Ryugu in June 2018 and is due to begin collecting samples this year.

**CHANG'E-4**
The probe, carrying the Yutu-2 rover, became the first instrument to explore the far side of the Moon.

## HAYABUSA2

Its predecessor was the first time we'd returned a sample of an asteroid to Earth. But that mission was plagued with problems, so hopefully this time things will run more smoothly and return more material for scientists to study.

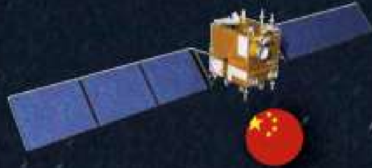
LAGRANGIAN POINT L2

## CHANG'E-4

On 3 January this year China's Chang'e-4 became the first probe to land on the far side of the Moon. Two weeks later, the probe sent back a grainy photo showing tiny green shoots sprouting from a cotton seed in its Lunar Micro Ecosystem experiment – the first time a plant has been grown on another world. Sadly, the shoot didn't survive but its germination could be an important step on the way to establishing a permanent base on the Moon.

150 MILLION KM FROM SUN

228 MILLION KM FROM SUN



**CHANG'E-2**
Exploring the Moon and asteroids. Currently 100 million kilometres from Earth.

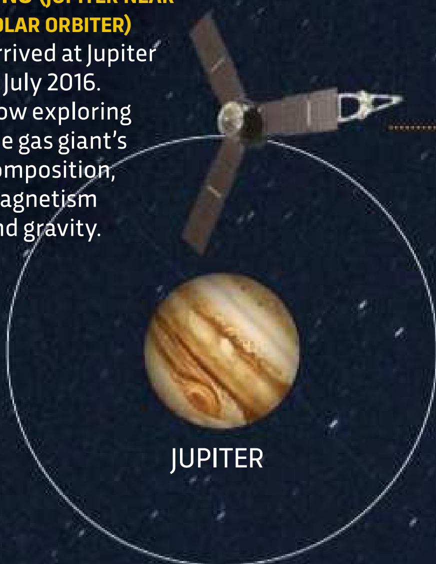
## VOYAGER 1

In August 2012, it was confirmed that Voyager 1 had reached intertellar space. But it still has a long way to go before it reaches the Oort Cloud – technically still part of the Solar System. Instead, it has left the magnetic influence of the Sun, as the solar wind is lost in the winds of other nearby stars.

**VOYAGER 2**
Explored Jupiter, Saturn, Uranus and Neptune. The probe entered interstellar space in November 2018.

**VOYAGER 1**
Explored Jupiter and Saturn and is now in interstellar space some 21 billion kilometres from Earth.

**JUNO (JUPITER NEAR-POLAR ORBITER)**
Arrived at Jupiter in July 2016. Now exploring the gas giant's composition, magnetism and gravity.





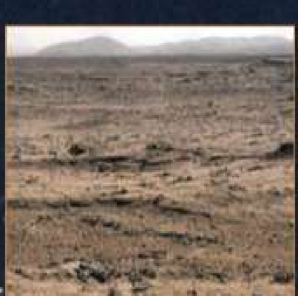



## JUNO

Since arriving at Jupiter in the summer of 2016, Juno has sent back stunning high-definition images of the Solar System's largest planet. Its scientific objectives include exploring Jupiter's composition, investigating the existence of a solid core and deciphering why the planet's Great Red Spot is shrinking. Three aluminium Lego figures were carried along for the ride – one of the Roman god Jupiter, his wife Juno and Galileo, the first astronomer to observe the planet through a telescope.


**OSIRIS-REX**
Currently surveying the asteroid 101955 Bennu. It's expected to return a sample of Bennu's surface to Earth in 2023.

**NEW HORIZONS**
Explored Pluto in 2015 before proceeding to the Kuiper Belt object 2014 MU69 (now known as Ultima Thule) and photographing it during a flyby in January 2019.



## CURIOSITY

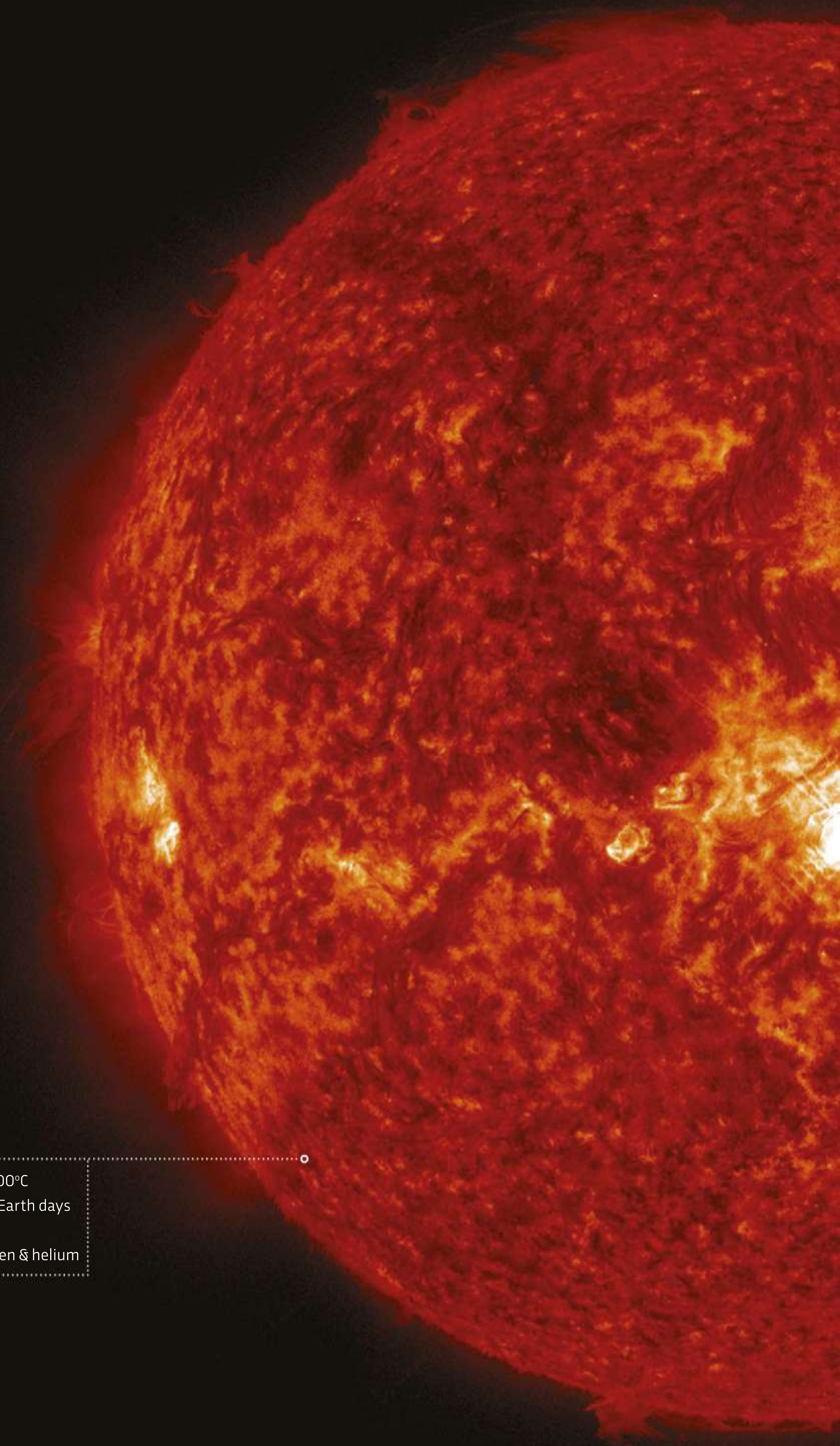
As planetary missions go, few are as daring as Curiosity. Previous Martian rovers had been lowered onto the Martian surface inside inflatable balls, which slowly deflated to leave the machine to roll out onto Mars. But Curiosity was gently lowered onto the surface via an intricate 'sky crane'. Curiosity has now experienced two full cycles of the Martian seasons. As of November 2018, it was exploring Vera Rubin Ridge and about to drill into the surface at Lake Orcadie.

## NEW HORIZONS

When the mission set off in early 2006, the world it was heading to was still a planet. Later that year, however, Pluto was downgraded to dwarf planet status. New Horizons finally ended its nine-year journey to the Kuiper Belt in 2015. For the first time, we had crisp, close-up images of Pluto. Scientists were left baffled by its smooth, crater-free surface, suggesting it must have some kind of geological activity that constantly re-sculpts its surface.

**779 MILLION KM FROM SUN** · **1.43 BILLION KM FROM SUN** · **2.87 BILLION KM FROM SUN** · **4.50 BILLION KM FROM SUN** · **5.91 BILLION KM FROM SUN**

# THE SUN

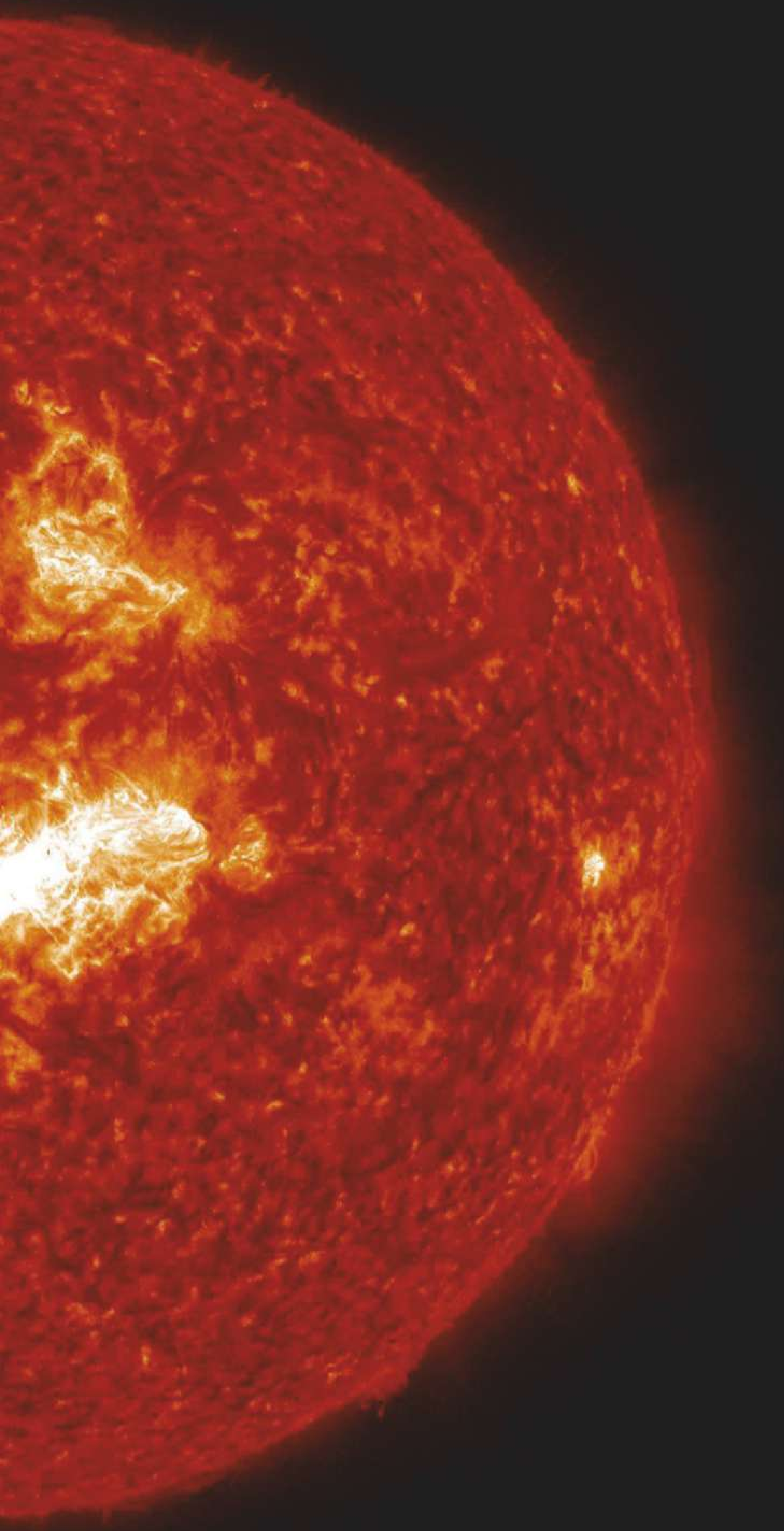


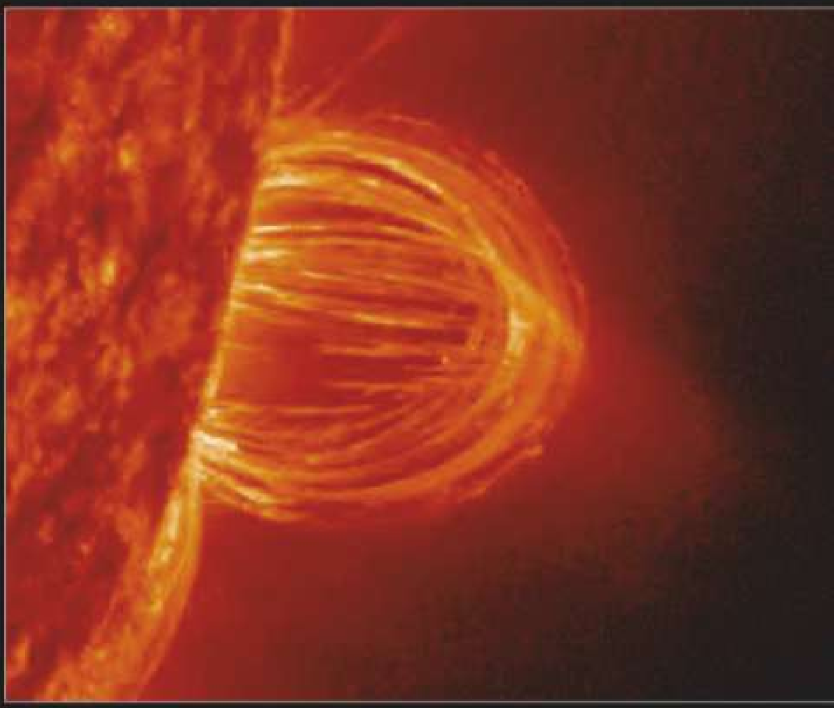
At about 1,400,000km in diameter, the Sun is the biggest and most influential body in its system. Weighing some two million trillion trillion kilograms, it makes up 99.98 per cent of the mass in the Solar System, though in astronomical terms it is only a medium-sized star. This huge bulk causes intense pressure in the Sun's core, where temperatures can reach over 1,000,000°C. By the time the plasma (charged hydrogen and helium particles) reaches the surface, however, it has cooled to a mere 5,500°C – still white hot, emitting light powerful enough to provide the Solar System with its energy.

The Sun's extreme conditions create a highly dynamic object. Its outer layers are constantly being shed, creating a solar wind of high-energy particles that sweeps through the Solar System. Meanwhile, inside the star, the plasma's motion creates a giant magnetic field that extends 18 billion kilometres from the Sun. Every 11 years this field flips, causing matter from deep inside the star to bubble up to the surface, exploding in spectacular solar flares.

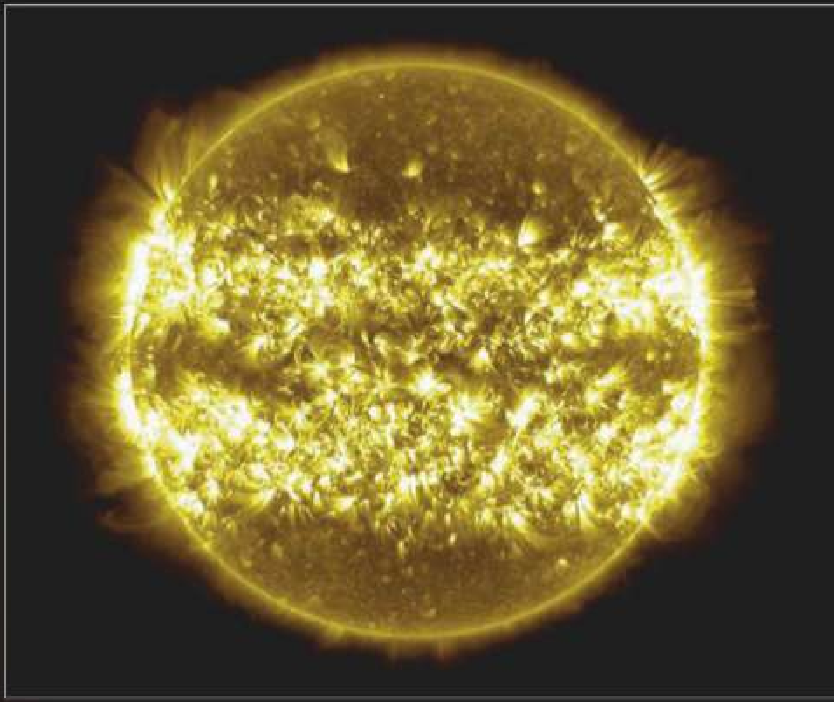
**SURFACE TEMPERATURE:** 5,500°C
**TIME TO ROTATE ONCE:** 25.38 Earth days
**DIAMETER:** 1,391,000km
**ATMOSPHERE:** Mainly hydrogen & helium

NASA/SDO, NASA/ROYAL OBSERVATORY BELGIUM/SIDC, NASA/GODDARD SPACE FLIGHT CENTER, SOHO/MDI (ESA & NASA)

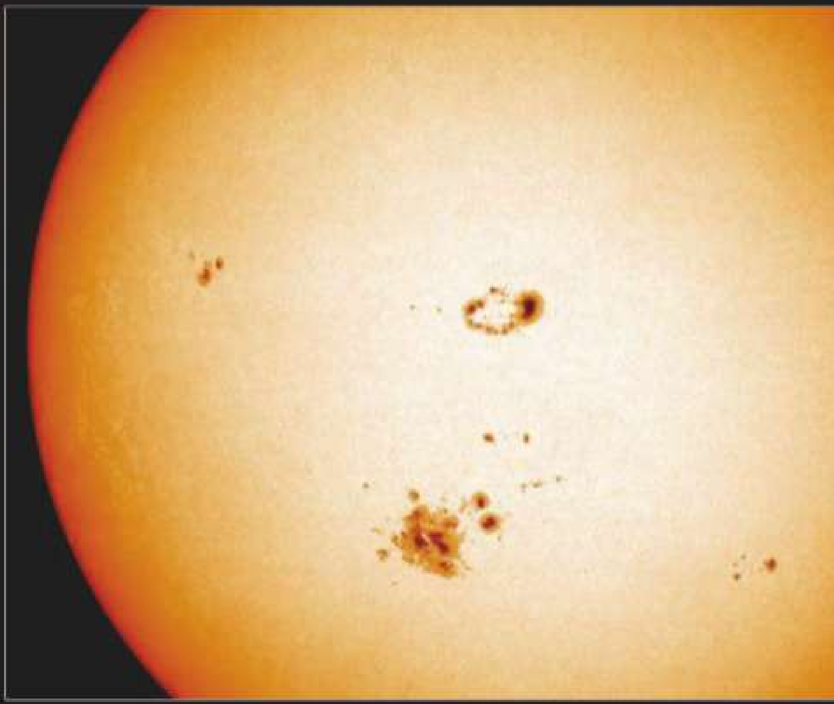




▲ A solar flare captured by NASA's Solar Dynamics Observatory



▲ Made up of 25 separate images, this shows a year of solar activity



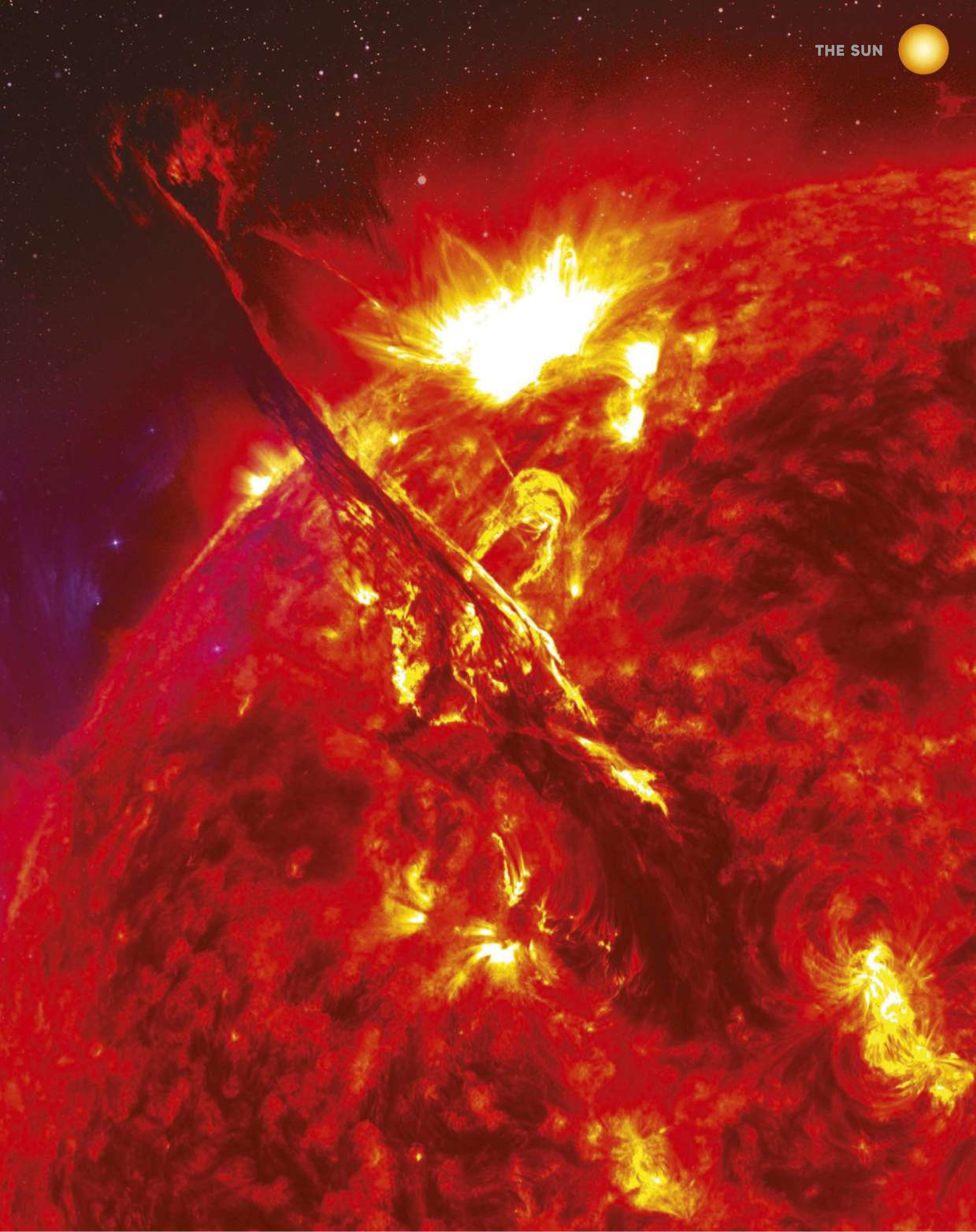
▲ Sun spots appear dark as they are cooler than other parts of the surface

# MISSION INTO THE SUN

We've visited Pluto and the outer reaches of the Solar System, and our rovers are trundling over the surface of Mars. Yet the Sun has remained stubbornly out of reach... until now

WORDS: **STUART CLARK**

ILLUSTRATION: ANDY POTTS



Last summer, NASA launched one of its most ambitious space missions: the Parker Solar Probe. Travelling at a blistering 720,000km/h (450,000mph), the spacecraft is diving repeatedly closer to the Sun than any previous spacecraft in history – so close that the probe team refers to it as 'touching' the star. In fact, it is diving in and out of the Sun's atmosphere, known as its corona. And it's not going to be alone up there.

The European Space Agency (ESA) is sending a solar mission of its own, scheduled for launch in 2020. Solar Orbiter will not go as close to the Sun as its NASA counterpart, but it will still be bathed in intense sunlight, almost 500 times that experienced by a spacecraft in Earth's orbit. Unlike Parker Solar Probe, which spends only a short amount of time in the fierce heat as it dives in and out, Solar Orbiter will stay put for years, watching and measuring the Sun.

Both of these missions have a key goal: to find out more about the way electrified gas, known as plasma, is launched from the Sun's atmosphere out into space. This continuous stream is known as the solar wind. It carries energy and the Sun's magnetic field through space, and understanding it could solve a problem that's been mystifying scientists for decades and could be the key to safeguarding our technological society.

**Without advance warning, a huge solar flare, carried by the solar wind, could cause $2tr worth of damage in the US alone**

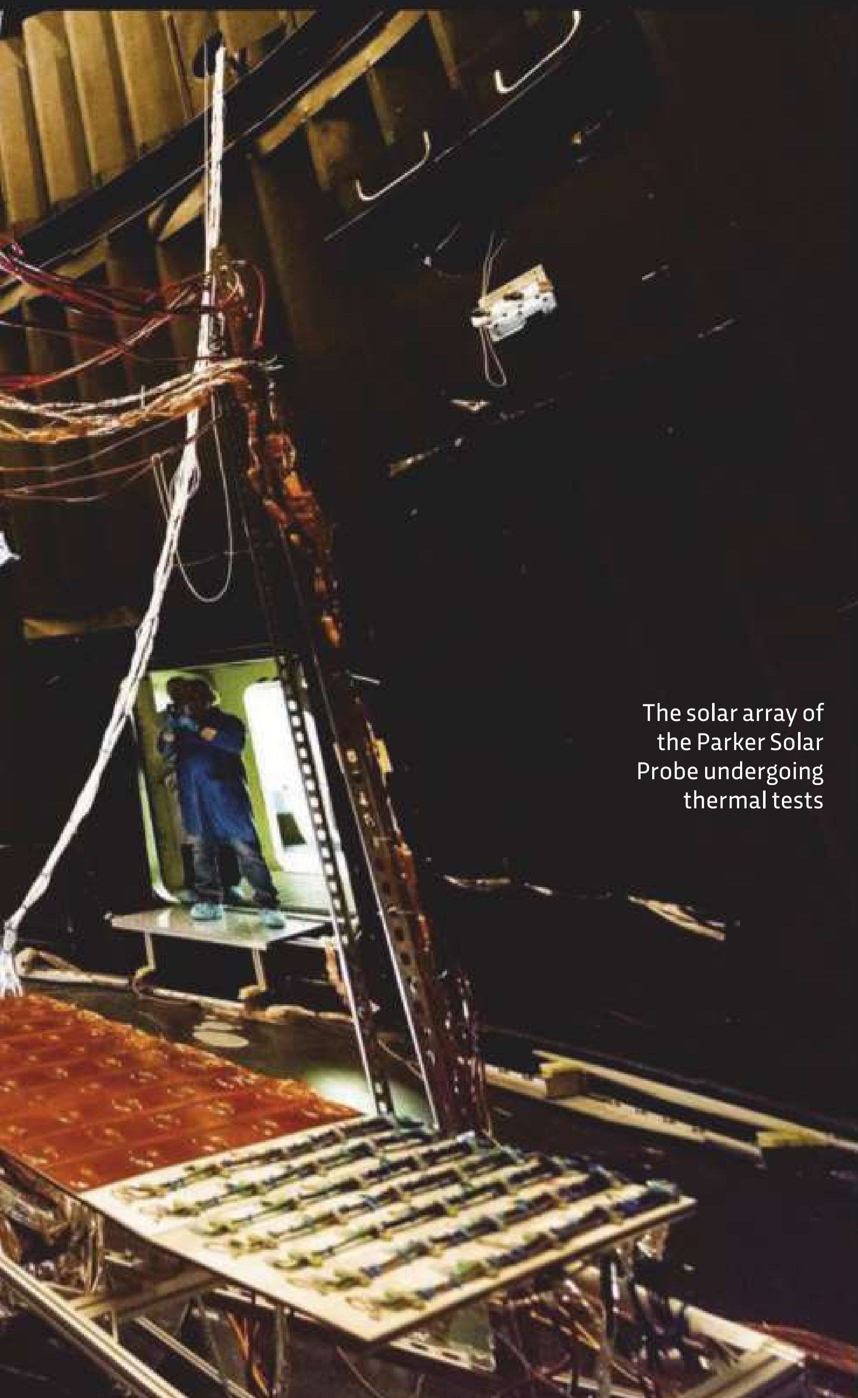
#### WHAT A WIND

When the solar wind collides with Earth, it can disrupt or even destroy electrical technology in orbit and on the ground.

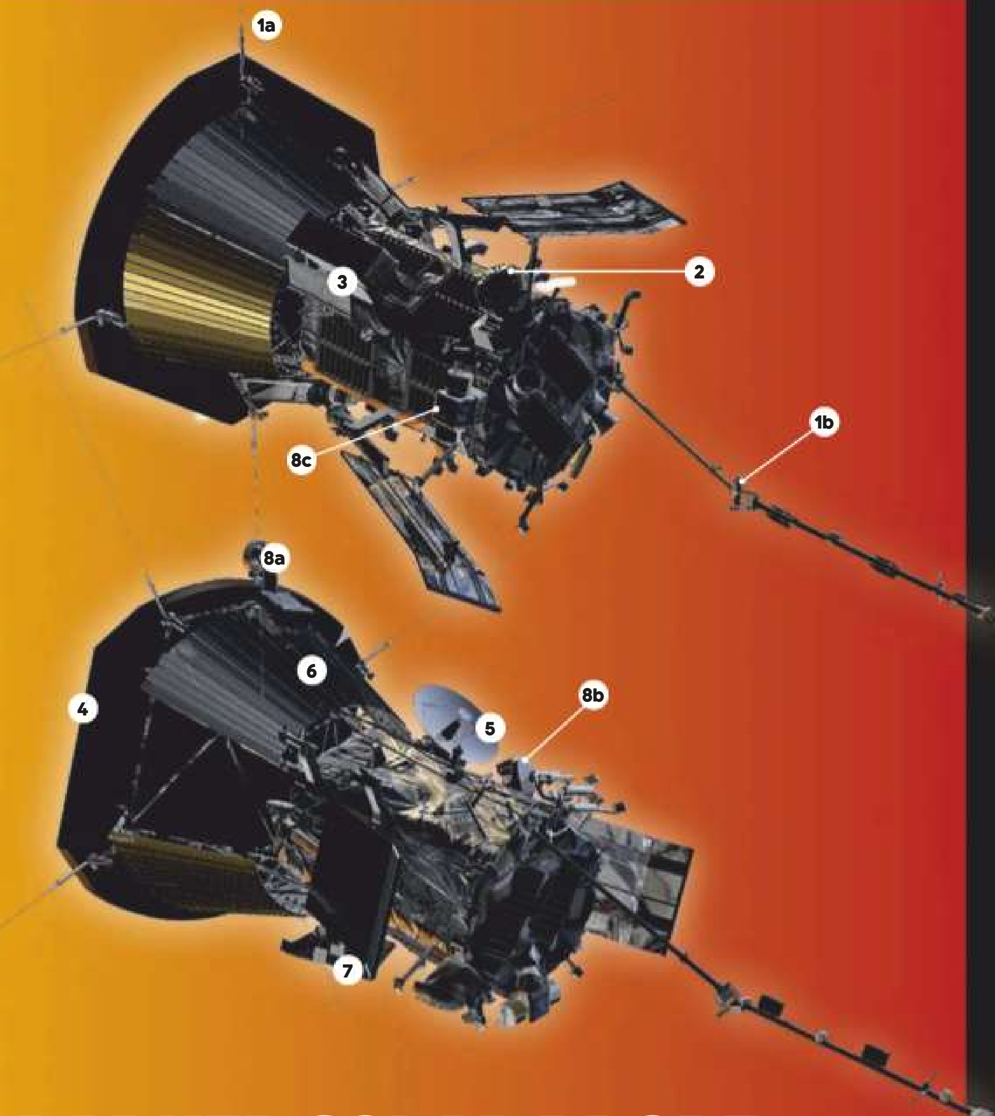
The Carrington Event, which took place in 1859, is the greatest of these so-called solar storms on record. Back then, society was more low-tech, but the global telegraph network went down and compasses spun uselessly.

Yet while solar storms of this magnitude only happen once every couple of hundred years, smaller storms happen more frequently. Most of these cause little disruption, but all have an effect. In March 1989, for example, a small solar storm severely damaged a power transformer on the Hydro-Québec power system. It took down their power grid for more than nine hours as emergency repairs were carried out. And more recently, in 2003, a series of solar storms that took place

NASA ILLUSTRATION: ACUTE GRAPHICS



The solar array of the Parker Solar Probe undergoing thermal tests




## PARKER SOLAR PROBE

**1 FIELDS EXPERIMENT**
Makes direct measurements of electric and magnetic fields and waves in the solar wind, and of density fluctuations and radio emissions.

**2 INTEGRATED SCIENCE INVESTIGATION OF THE SUN (ISIS)**
Observes highly accelerated electrons, protons and heavier particles, and correlates them with solar wind and coronal structures.

**3 WIDE-FIELD IMAGER FOR SOLAR PROBE (WISPR)**
Provides images of the solar wind, shocks and other plasma structures as they approach and pass the spacecraft.

**4 THERMAL PROTECTION SYSTEM (TPS)**
An 11.43cm-thick carbon-composite shield that will withstand temperatures outside the spacecraft that reach nearly 1,377°C.

**5 HIGH GAIN ANTENNA**
Used to communicate with Earth. The downlink data rate when close to the Sun will be around 167kb/s. Not much compared to modern broadband speeds.

**6 SOLAR ARRAY COOLING SYSTEM**
Operating in 475 times the solar intensity experience in Earth orbit, the solar arrays are cooled by a $4m^2$ radiator that sheds waste heat into space.

**7 SOLAR ARRAYS**
Although just $1.55m^2$ in area, the solar arrays generate 388W of electrical power at their closest approach to the Sun.

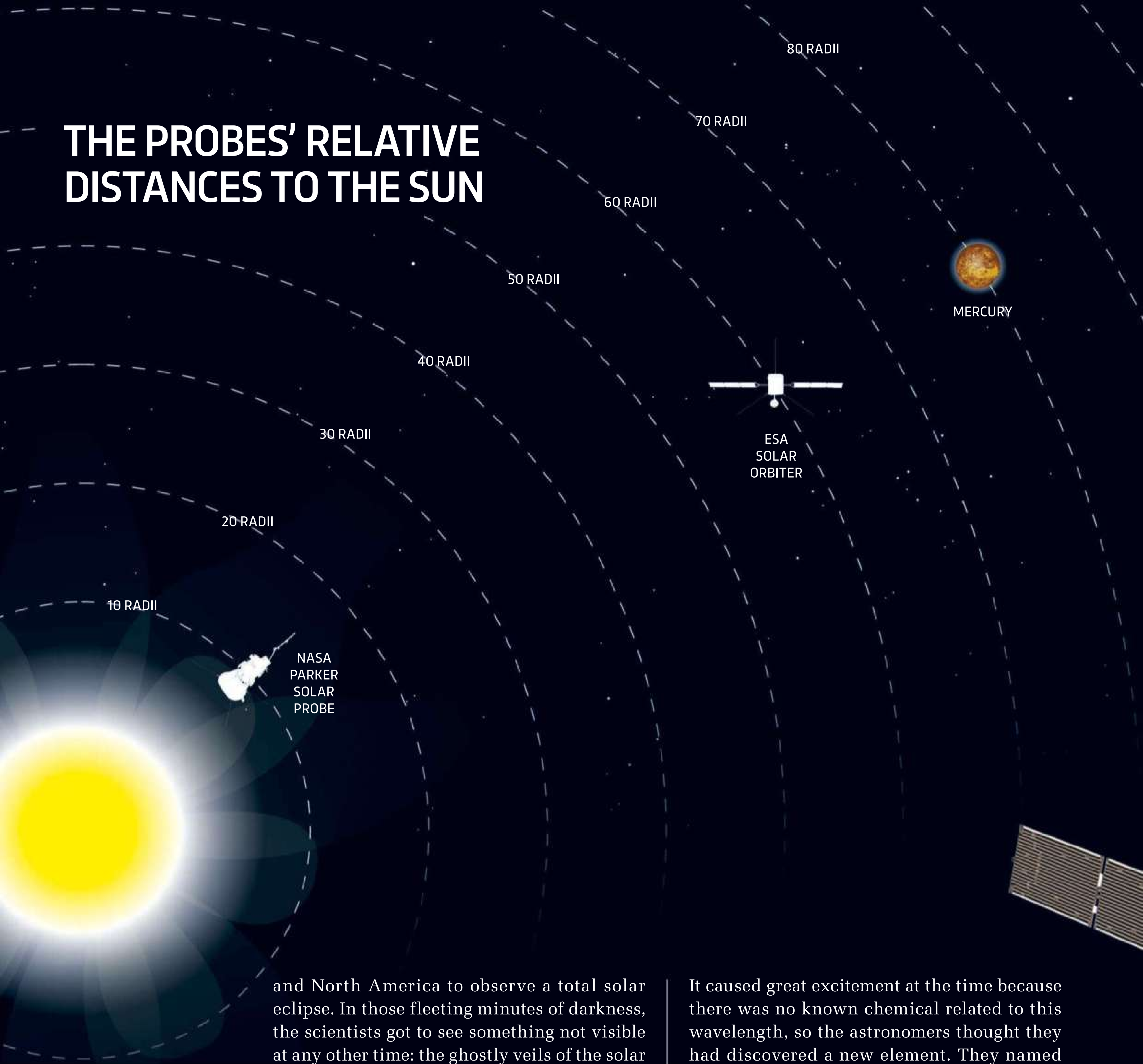
**8 SOLAR WIND ELECTRONS ALPHAS AND PROTONS (SWEAP) INVESTIGATION**
Counts the most abundant particles in the solar wind and measures their properties such as velocity, density and temperature.

around the Halloween period caused more than half of NASA's satellites to malfunction in some way, while aeroplanes had to be re-routed away from polar latitudes because of the large amounts of radiation associated with the intense aurora.

One recent study by the US National Academy of Sciences found that without advance warning, a huge solar flare, carried by the solar wind, could cause $2tr worth of damage in the US alone, and it would not be quick to fix. The report found that such an enormous solar flare could cause so much damage to power stations that the US eastern seaboard could be left without power for a year. Europe is similarly vulnerable.

While studying the Sun has never been more timely, the desire to do so stretches back before the space age to the 19th Century, when a solar mystery was uncovered. On 7 August 1869, astronomers gathered across Russia

# THE PROBES' RELATIVE DISTANCES TO THE SUN




Parker Solar Probe will 'dive' as close as 10 solar radii to the Sun, whereas Solar Orbiter will remain a constant 60 radii away

and North America to observe a total solar eclipse. In those fleeting minutes of darkness, the scientists got to see something not visible at any other time: the ghostly veils of the solar corona, the Sun's outer atmosphere. It was an object of fascination for the astronomers of the day. Two of the astronomers, Charles Augustus Young and William Harkness, were using spectroscopes to split the coronal light into its constituent wavelengths. They knew that the various chemical elements gave out light at specific wavelengths, and by measuring these 'spectral lines' they would be able to establish the chemical components of the corona. Working independently, they both discovered a green spectral line with a wavelength of 530.3nm. It caused great excitement at the time because there was no known chemical related to this wavelength, so the astronomers thought they had discovered a new element. They named it coronium.

It turned out that Young and Harkness were wrong, yet it wasn't until the 1930s that scientists understood why. Astrophysicists Walter Grotrian and Bengt Edlén conducted laboratory experiments and found that iron could give out that green light, but only if it were heated to an extraordinarily hot 3,000,000°C, turning it into plasma. With this realisation the real mystery was born. What exactly is heating the Sun's corona to 3,000,000°C? The magnitude of the problem

ESA ILLUSTRATION: ACUTE GRAPHICS

is enormous because the surface of the Sun is a mere (astronomically speaking) 5,500°C. "It defies the laws of physics and nature. It's like water flowing uphill. You move away from a heat source and it should get cooler not hotter," says Nicola Fox, mission project scientist at the Johns Hopkins University Applied Physics Laboratory. "What happens in this region that suddenly accelerates all of this coronal material to temperatures exceeding 3,000,000°C? It is mystery number one," says Fox.

And if that wasn't a big enough conundrum, there is a second, related mystery. The gas breaks away from the Sun just where the temperature peaks. "If you think of the Sun as a giant gravitating star, it is going to hang onto its material. And yet the plasma is able to break away and move out and bathe all of the planets," says Fox.

This solar wind that Fox refers to is made mostly of hydrogen and helium. The iron that betrayed the corona's great temperature actually makes up just a tiny fraction. The solar wind carries with it the Sun's magnetic field and streams out into space at about 1,600,000km/h. It bathes the planets, and when it collides with the Earth, it sparks the stunning auroras that shine in the polar skies.

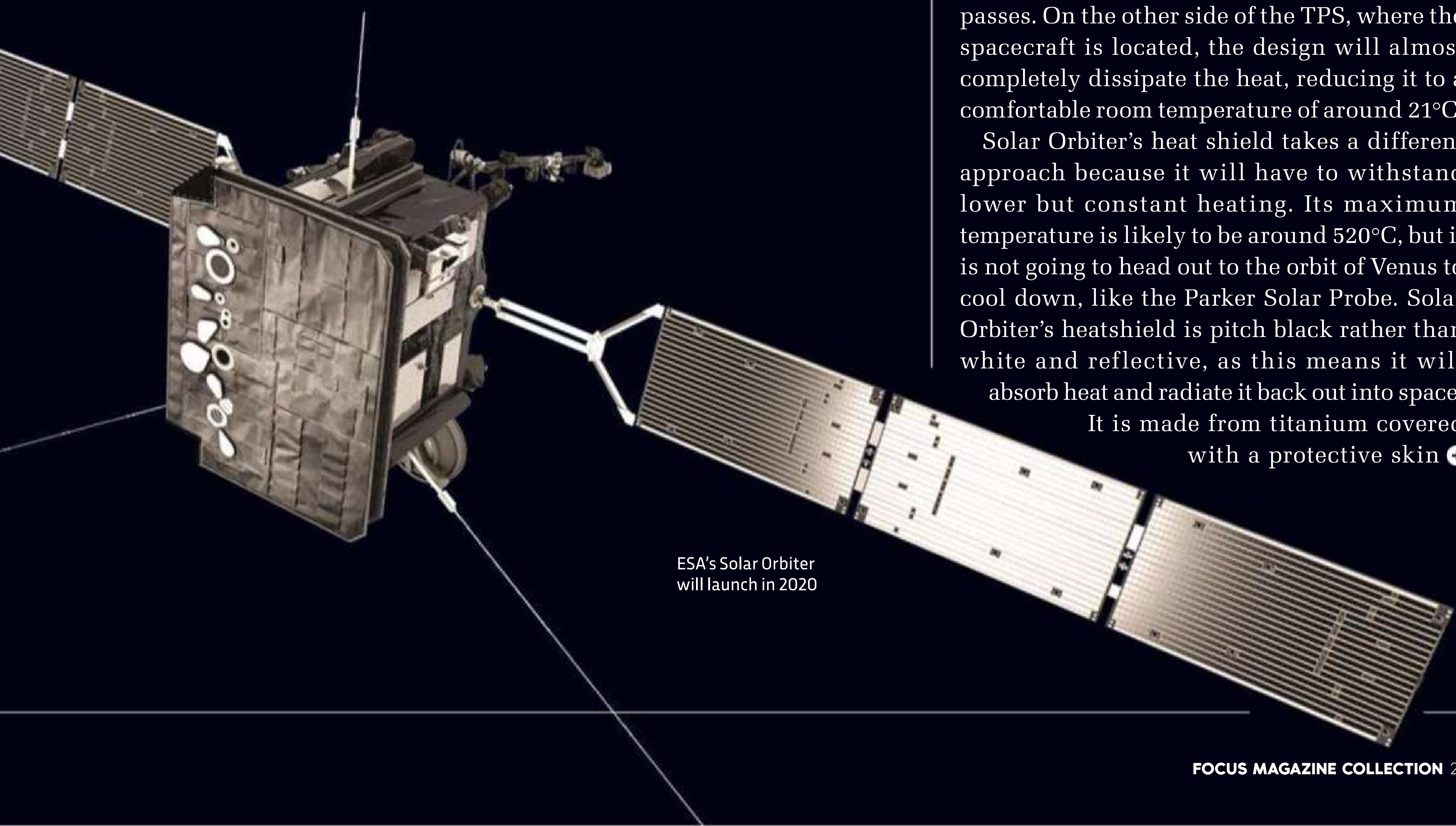
***Travelling at a blistering 720,000km/h, the spacecraft will repeatedly dive closer to the Sun***

**STAY COOL**

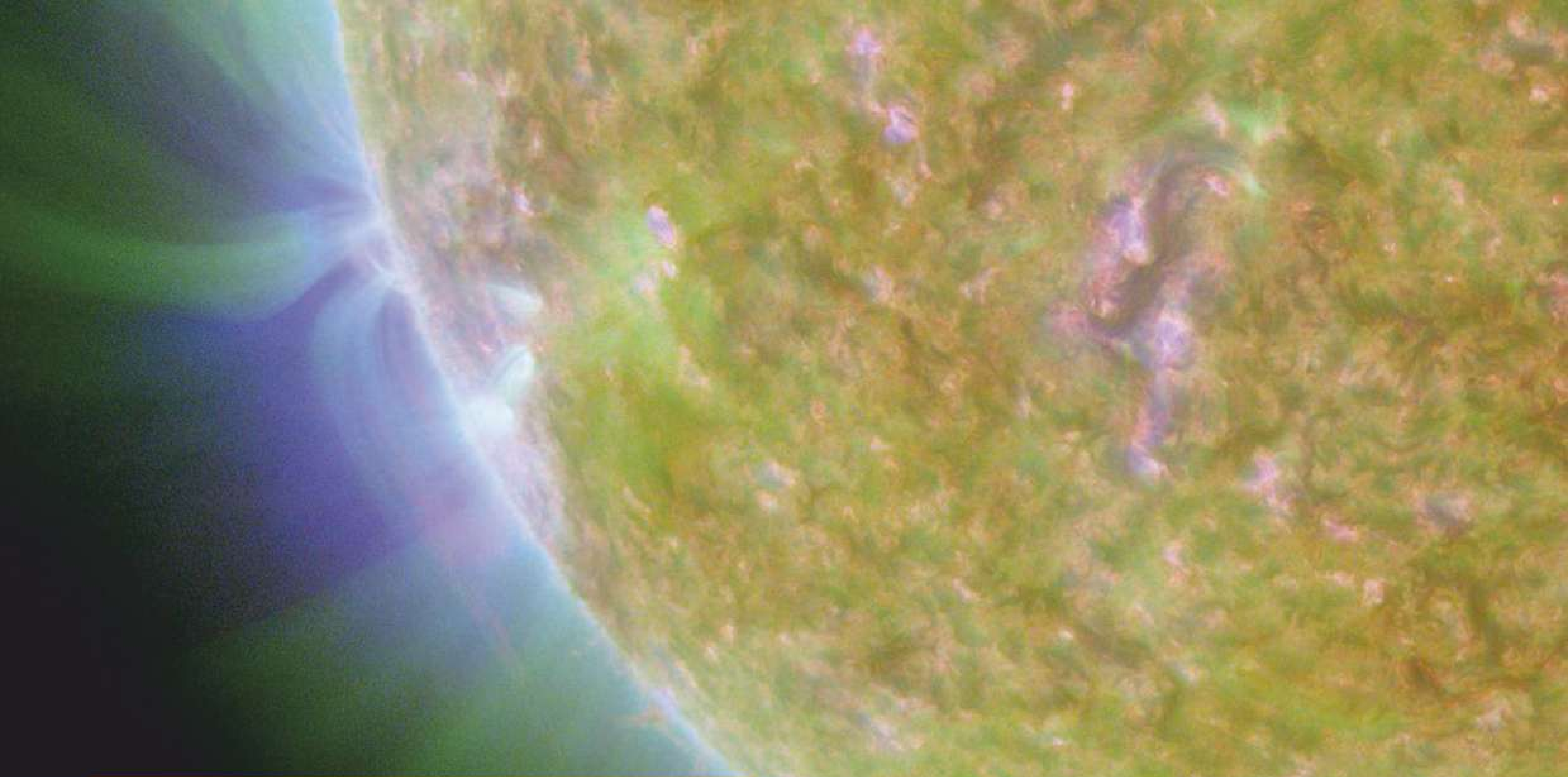
Astronomers say that the acceleration of the solar wind occurs at about 10 solar radii (one solar radius is equal to the radius of the Sun). "That's where Parker Solar Probe is diving, it's a scientifically important region of space," says Imperial College London's Prof Tim Horbury, who is a co-investigator on Parker Solar Probe's FIELDS instrument.

Through its series of extraordinarily close encounters with the Sun, Parker Solar Probe will repeatedly explore this key region. It can survive these plunges thanks to an innovative thermal protection system (TPS). This heat shield is made of two plates separated by a layer of carbon foam. The layer that faces the Sun is white and reflective. The foam itself is diffuse and light, and is composed of 97 per cent air. It was developed and manufactured especially for the spacecraft and is one of the key technologies that has enabled the mission to take place. It is just over 11cm thick, and will be heated to around 1,377°C during its close solar passes. On the other side of the TPS, where the spacecraft is located, the design will almost completely dissipate the heat, reducing it to a comfortable room temperature of around 21°C.

Solar Orbiter's heat shield takes a different approach because it will have to withstand lower but constant heating. Its maximum temperature is likely to be around 520°C, but it is not going to head out to the orbit of Venus to cool down, like the Parker Solar Probe. Solar Orbiter's heatshield is pitch black rather than white and reflective, as this means it will absorb heat and radiate it back out into space. It is made from titanium covered with a protective skin



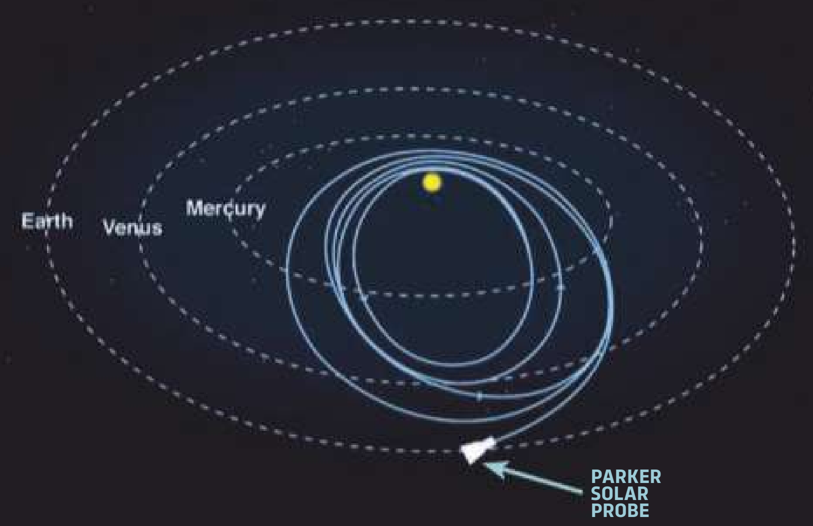
ESA's Solar Orbiter will launch in 2020



## THE ORBITAL PATHS

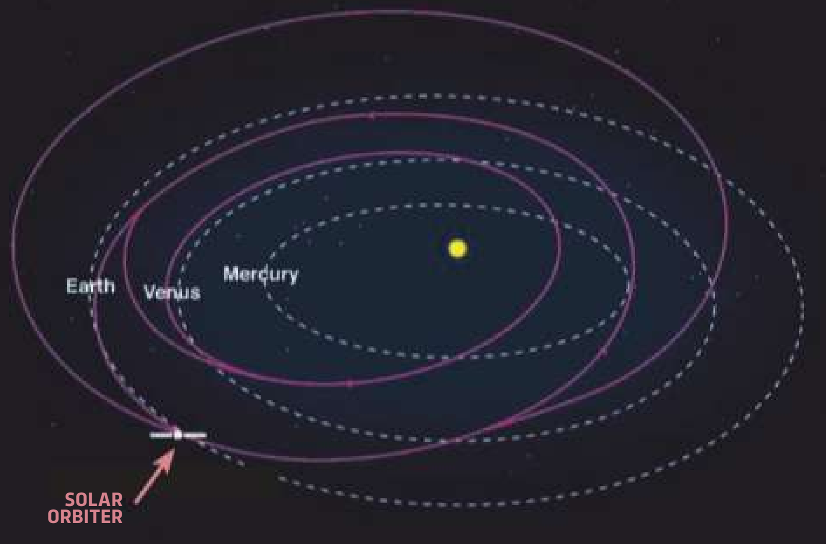
**PARKER SOLAR PROBE** (NASA)

LAUNCH DATE: August 2018




**SOLAR ORBITER** (ESA)

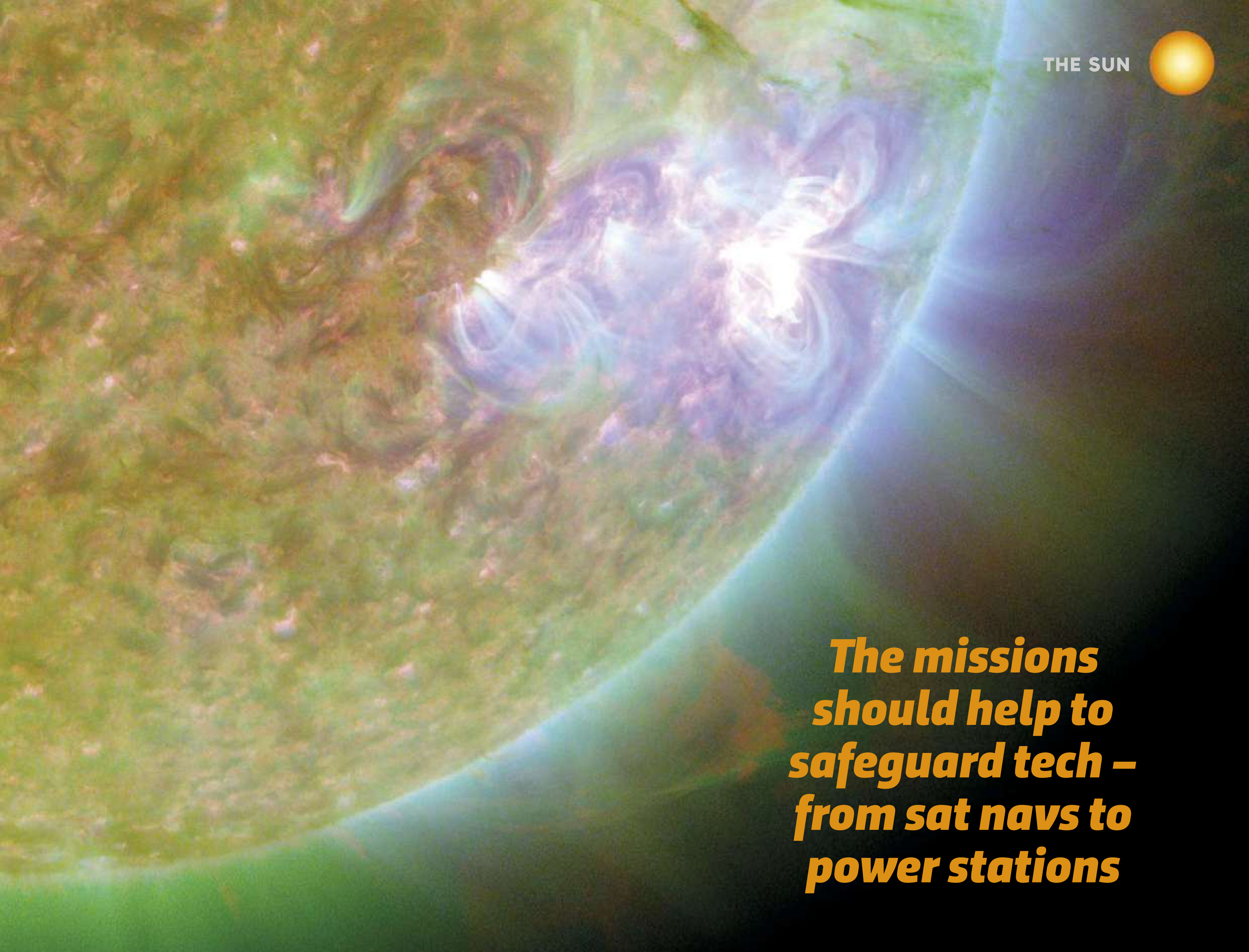
LAUNCH DATE: 2020




called SolarBlack, which is derived from a charcoal-based pigment made of burnt animal bones. This pigment is a type of black calcium phosphate and is widely used for fertiliser and metal alloy production, and for filtering heavy metals out of water. This skin keeps the European space probe safe so that it can operate continuously at a distance of 60 solar radii. Although this is six times further away than Parker Solar Probe's closest approach, there is a particular reason for choosing this distance. "It will go as close as you can go and still use telescopes to look at the Sun," explains Horbury. Parker Solar Probe's only telescope looks to the side to take images of the solar wind rushing by.

Solar Orbiter's telescopes will study the Sun's surface with a variety of instruments over a wide range of different wavelengths so that astronomers can determine the

NASA/SOHO ILLUSTRATION: ACUTE GRAPHICS



**The missions should help to safeguard tech – from sat navs to power stations**

surface gas's densities, temperatures and the magnetic field. It then contains a second suite of instruments that measure the same properties for the solar wind as it passes the spacecraft. Parker Solar Probe is designed to fly through the exact region of the Sun's atmosphere where it breaks its connection to the solar surface and becomes the solar wind. So by sharing their data the mission scientists can make the connection between events on the solar surface, the launching of the solar wind, and the downstream conditions.

### EARLY WARNING

Solar storms have shown how the interaction of the solar wind with Earth's magnetic field can severely damage important technology. So, while these missions to the Sun are likely to reveal all sorts of interesting data and maybe even new theories about our star, more crucially, they should help us to safeguard the tech we rely on every day – from telecommunications to sat-navs to power stations.

Currently, we get only 30 to 60 minutes warning from a NASA spacecraft called ACE. Once these two missions have performed their work, the hope is that this warning time will rise to a day or two. That's because solar storms are sparked by flares on the Sun that trigger a sudden ejection of material from the corona into the solar wind. It takes a day or two for this eruption to cross space, so knowing the way in which the solar wind is launched is critical if we are going to calculate the severity of any incoming solar storms. It could also give us more time to prepare and protect any important electrics.

"The data will make improvements to models," says Fox. "A few years from now when we see a big event, the model will accurately tell us what is coming to Earth."

BBC WORLD SERVICE

Listen to an episode of *Click* about the Parker Solar Probe mission **bbc.in/2SGXiQ1**

**Dr Stuart Clark** is an astronomy writer with a PhD in astrophysics. His latest book is *The Unknown Universe*.

# MERCURY

## Rich in resources and fuel, mining this peculiar planet could be our ticket out of the Solar System

WORDS: **STEPHEN BAXTER**

The innermost planet in our Solar System, was once an enigma. For years, its proximity to the Sun made it difficult for astronomers to observe – but the Space Age changed all that. NASA's MESSENGER, the second space probe to Mercury and the first orbiter, was launched in 2004 and orbited the planet from 2011 to 2015. The data it returned gave us real knowledge about Mercury. In 2016, Mercury passed between the Sun and Earth – the first transit in 10 years. And then last year, the Japanese and European space agencies launched BepiColombo, which will arrive at the planet in 2025.

Superficially, Mercury's surface might seem like the Moon: a small, airless world with a rocky surface distorted by huge, ancient craters. But the details vary, because of the planet's different location and composition. On Mercury, there are peculiar linear features called rupes (Latin for 'cliffs') that resemble wrinkles on a shrivelled apple – and it's thought that is pretty much how the rupes formed, with the planet shrinking by a kilometre or so as it cooled.

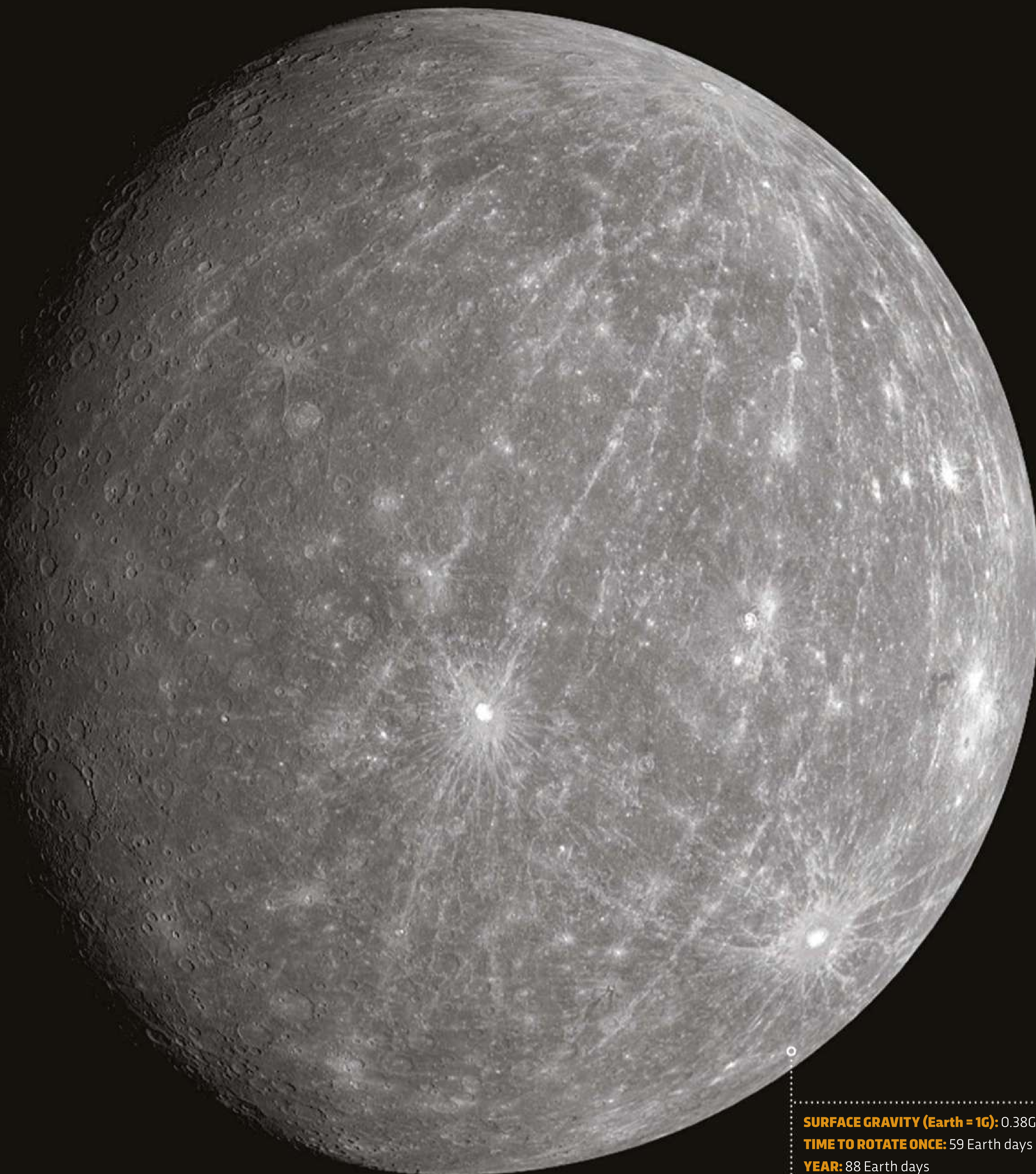
Although the planet is only a little larger than the Moon, its gravity is about twice as high. Mercury was once a more massive world with, like Earth, an iron core and a rocky mantle. An immense collision with another young world may have stripped off much of that mantle, leaving the planet with an outsize core and a higher density to match.

Mercury takes 88 Earth days to orbit the Sun, and rotates once on its axis every 59 Earth days. But standing anywhere on Mercury, you don't see the Sun rise every 59 Earth days because of that short year. Mercury is so close to the Sun that tidal forces have locked in its rotation periods: three Mercury 'days' are the same as two Mercury 'years'. The net effect is that at any point on Mercury's surface you will only see a sunrise every 176 Earth days.

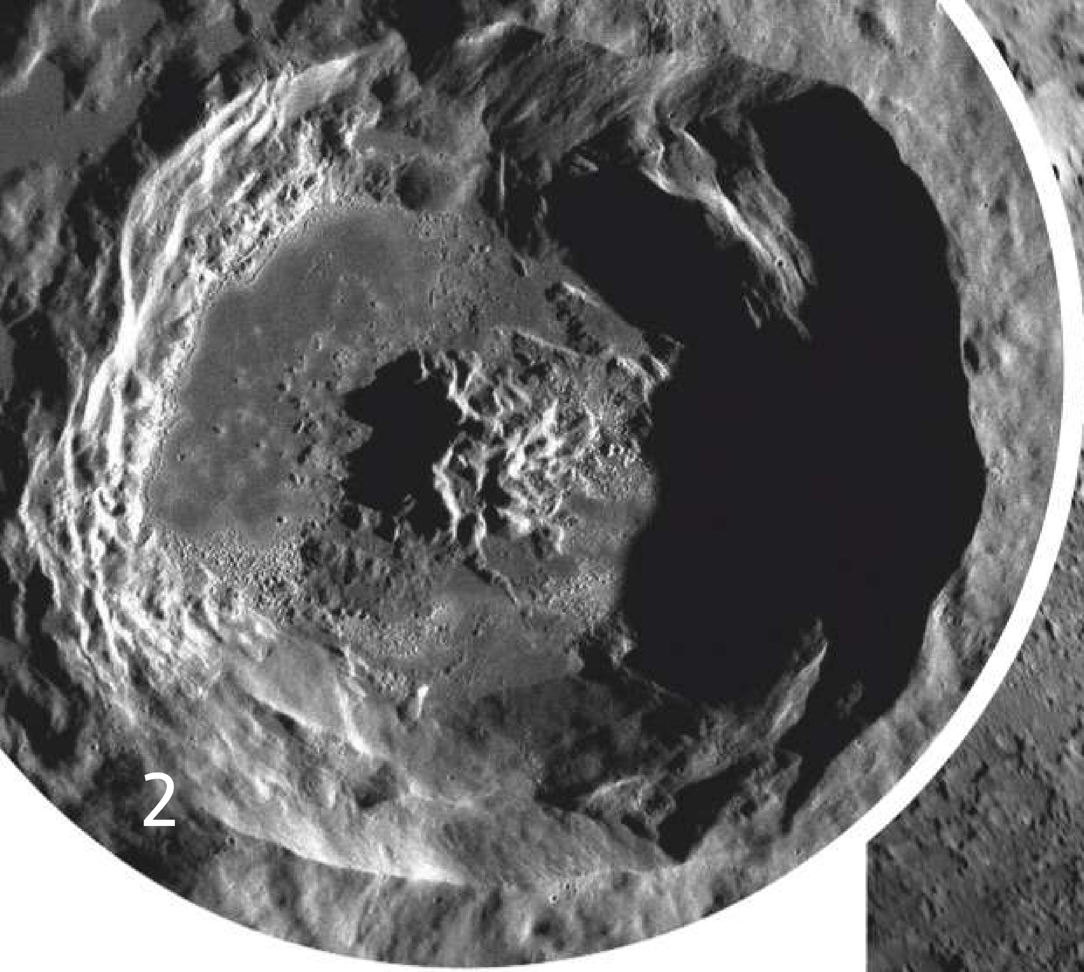
The long days and nights cause the climate of the planet to swing between extremes. During Mercury's day the Sun's heat roasts the surface seven times more

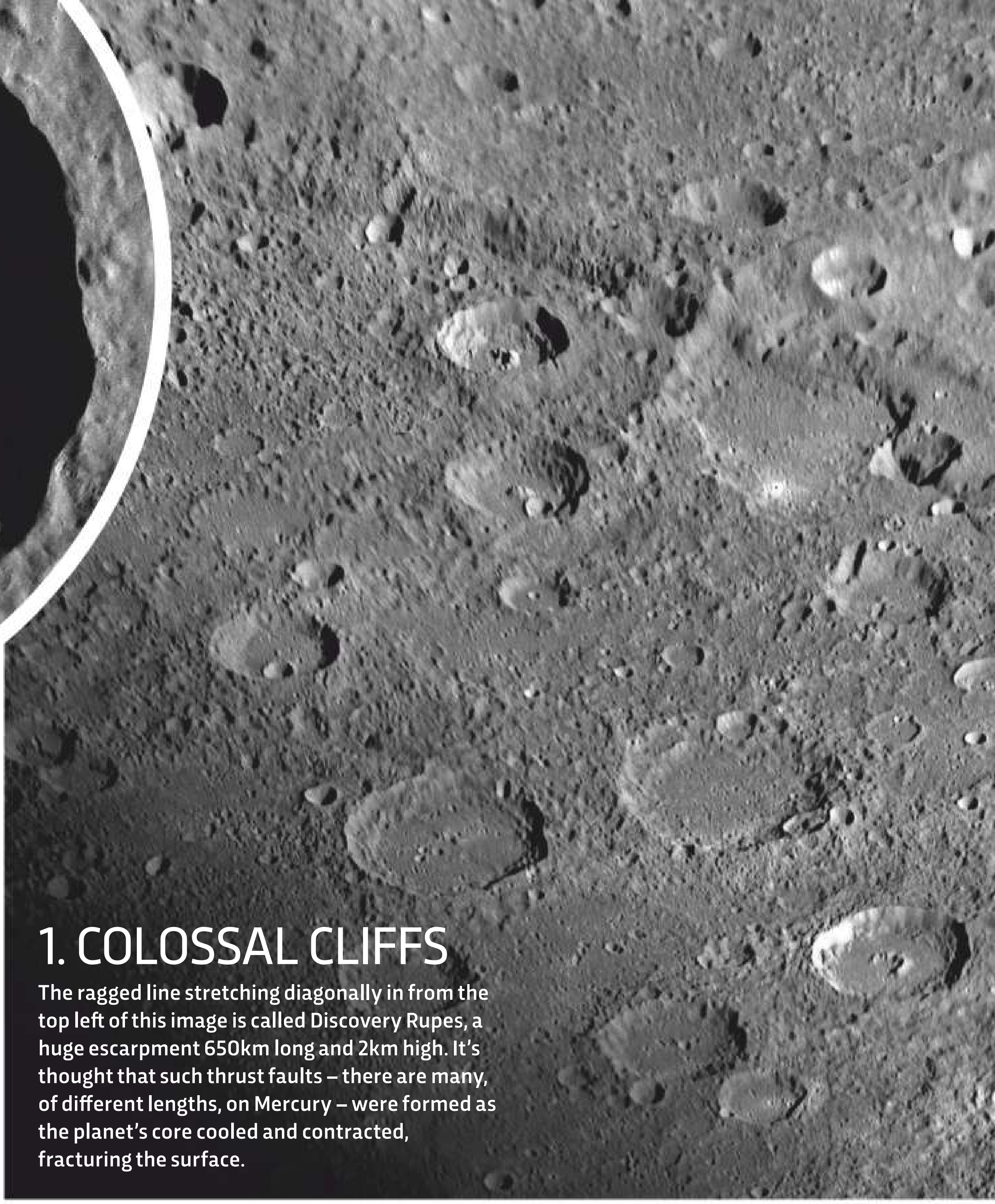
BepiColombo is composed of two separate orbiters that will work in different orbits to explore the planet and its environment

NASA, JAXA/ESA



**SURFACE GRAVITY (Earth = 1G):** 0.38G
**TIME TO ROTATE ONCE:** 59 Earth days
**YEAR:** 88 Earth days
**MOONS**: 0



## 1. COLOSSAL CLIFFS

The ragged line stretching diagonally in from the top left of this image is called Discovery Rupes, a huge escarpment 650km long and 2km high. It's thought that such thrust faults – there are many, of different lengths, on Mercury – were formed as the planet's core cooled and contracted, fracturing the surface.

***Water ice – life support for future colonists intent on mining Mercury's rich resources***

fiercely than it does on Earth, raising the temperature to over 420°C – hot enough for lead to melt. That intense heat and radiation long ago blasted away any vestiges of atmosphere: with no gases to help trap heat near the planet's surface, when night falls the temperature plummets to as low as -180°C.

Such extremes suggest it would be impossible to live on Mercury. But nature may have given future explorers a break. The planet has no axial tilt, so there are no seasons. This means that at the planet's poles, there may be craters where the Sun never shines. And there lies a miracle, discovered by MESSENGER: water ice, delivered by the impacts of comets and frozen in the permanent shadows – life support for future colonists intent on mining Mercury's rich resources. The planet also has energy aplenty in the form of concentrated sunlight. To capture as much energy as a square metre of solar-energy cells on Mercury would require six square metres on the Earth – and 60 square metres on Ceres – the dwarf planet that's often touted as a good candidate for resource extraction.

### MINERAL WEALTH

As for the resources, there is strong concern about the impact of mining on Earth, in terms of environmental cost; plus, resources extracted from Earth would be expensive to lift into space. So it would be far better to mine out there. That prospect may be coming closer, with the emergence of the Alliance for Space Development, led by the US's National Space Society, to press for legislation and initiatives to allow development of space resources.

Mercury's mantle has much the same composition as the Moon, which has been proposed as a good site to mine, because its surface is full of useful components such as

NASA/JOHNS HOPKINS UNIVERSITY/CARNEGIE INSTITUTION, NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/CARNEGIE INSTITUTION OF WASHINGTON X3

## 2. DEEP IMPACT

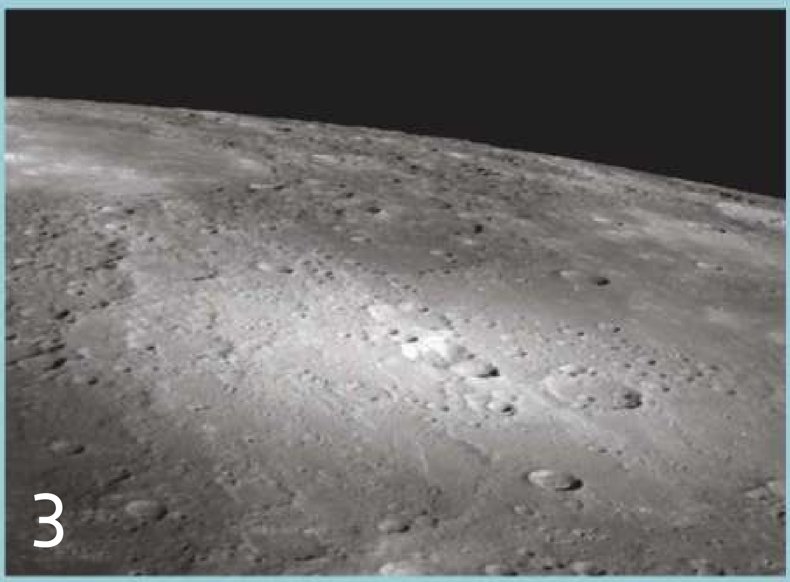
This crater lies within the Caloris Basin, an impact crater itself over 1,500km across and one of the largest in the Solar System. The violent collision that produced it flung debris over 1,000km from the crater edge. And on the opposite side of Mercury are strange hills, which may have been caused by shock waves from the impact rippling through the planet, cracking the ground on the other side.

## 3. VOLCANIC VENTS

Not all of the topographic features on Mercury's surface were created by meteoroid collisions. This image shows a bright area comprising what is believed to be pyroclastic material surrounding the vent that produced it, possibly a few billion years ago. The irregular-shaped formation at bottom right is an older vent.

## 4. PYROCLASTIC VENTS

The yellowish patches on this image depict pyroclastic vents. Though commonly seen across the planet, this is one of the largest such clusters, stretching across nearly 10° of Mercury's surface. These vents may have been the source of explosive eruptions driven by volcanic gases.





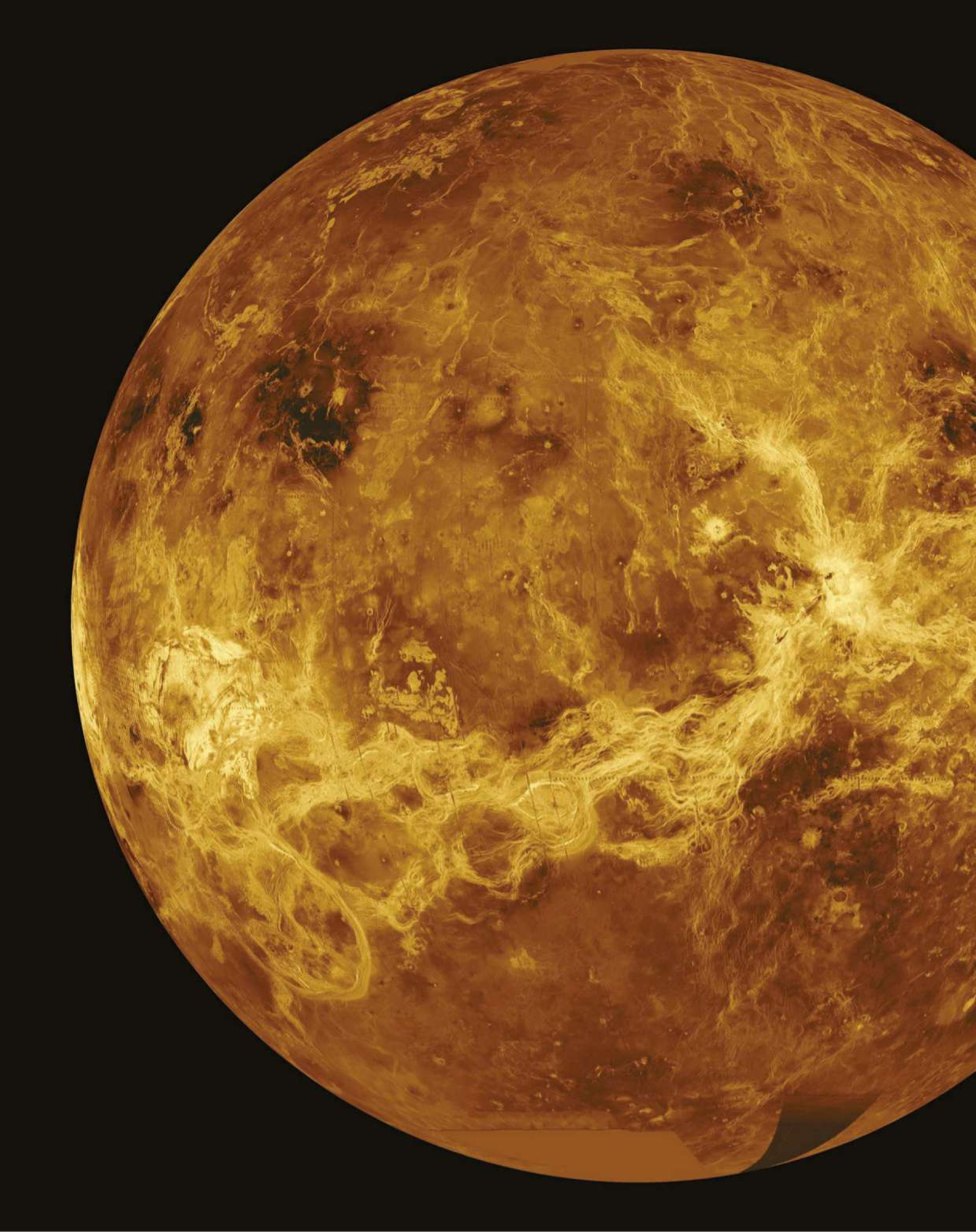
oxygen, calcium, magnesium, potassium, even heavy metals like titanium and aluminium. So techniques developed on the Moon could easily be transferred there. In addition, the huge amount of solar energy received by Mercury could be used to drive the mining operations themselves, and for firing packets of resources to sites across the Solar System – perhaps using 'mass drivers'. These electromagnetic sling-shots were first suggested by Arthur C Clarke. It might be more acceptable to mine remote Mercury than to scar Earth's Moon, plus Mercury's huge core – mostly iron, but rich in other metals – is only 600km down in some places, whereas the Moon's smaller core may be up to 1,400km down.

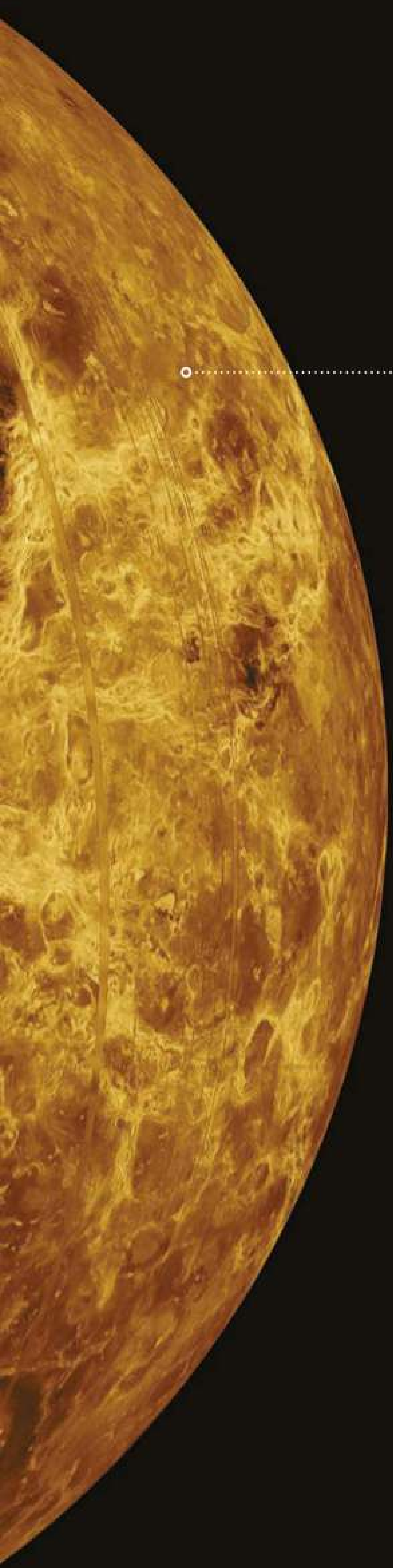
There are still more imaginative schemes. All that sunlight could be used as a free propulsion system. Imagine a solar sail, strong but thin, perhaps built out of Mercury's aluminium. When sunlight hits a reflecting surface, it exerts a pressure – as if the particles of light are rebounding from the surface and pushing it away. The effect is small, but it's useful, continuous and free. At the distance of Earth, a sail measuring 800m across would receive a light-pressure of about five Newtons, which is similar to the thrust of the low-drive ion-propulsion engines used on NASA's Dawn spacecraft. And the closer you get to the Sun, the greater the thrust – at Mercury you would get the same thrust with a sail measuring less than half that diameter. If you wished to ride a solar sail to Neptune, the most distant planet, it would be better to pay a visit to Mercury first to pick up the greater acceleration, and then sail outwards.

All these resources mean that some day Mercury may become the shipyard and principal port of the Solar System.

Listen to *Inside Science* discuss why BepiColombo is going to Mercury **bbc.in/2QQYKxF**

**Stephen Baxter** is a science fiction author and member of the British Interplanetary Society.





**SURFACE GRAVITY (Earth = 1G):** 0.91G
**TIME TO ROTATE ONCE:** 243 Earth days
**YEAR:** 225 Earth days
**MOONS:** 0

NASA

# VENUS

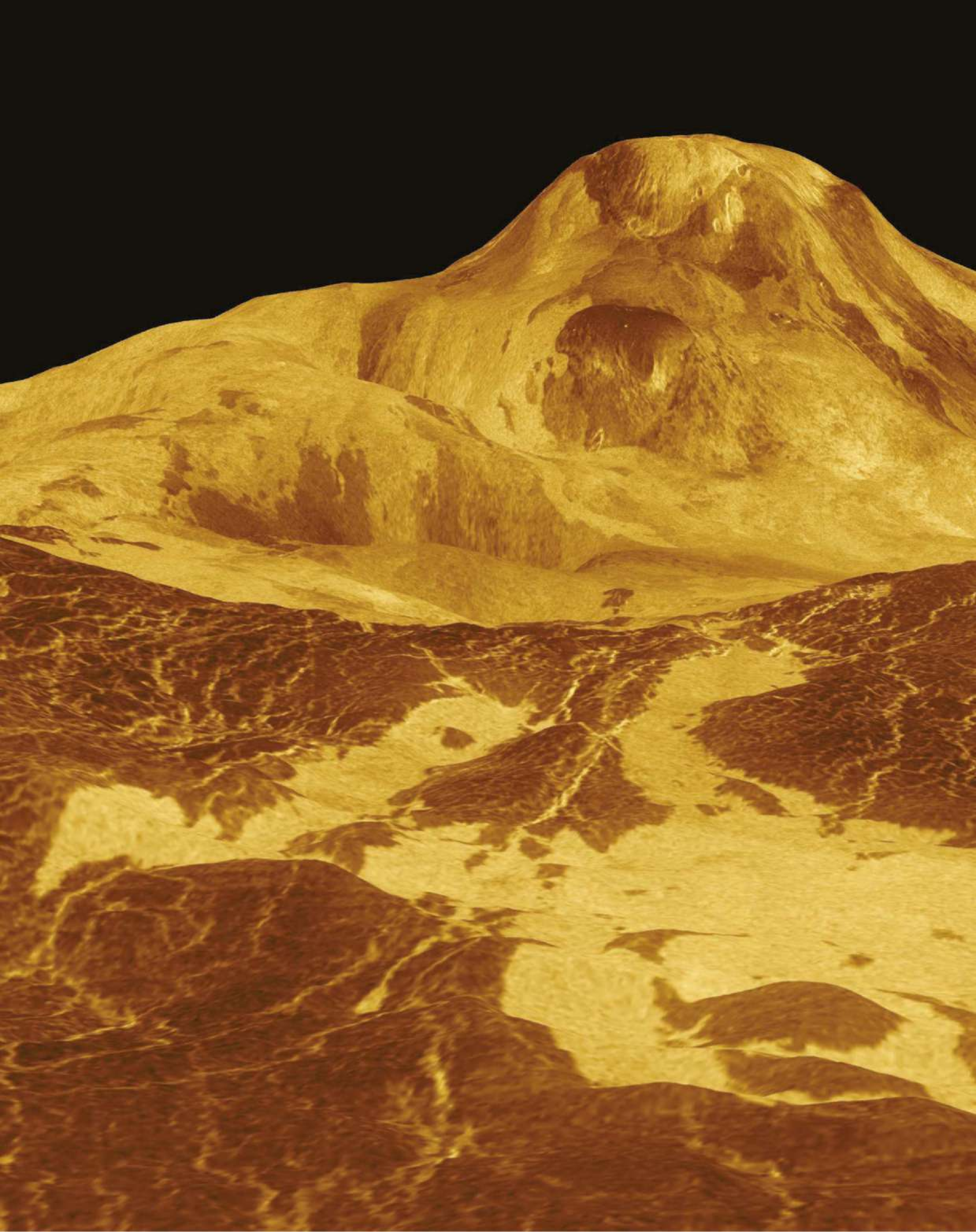
Earth's inner neighbour is still very much a mystery. But a host of planned missions will help reveal its secrets

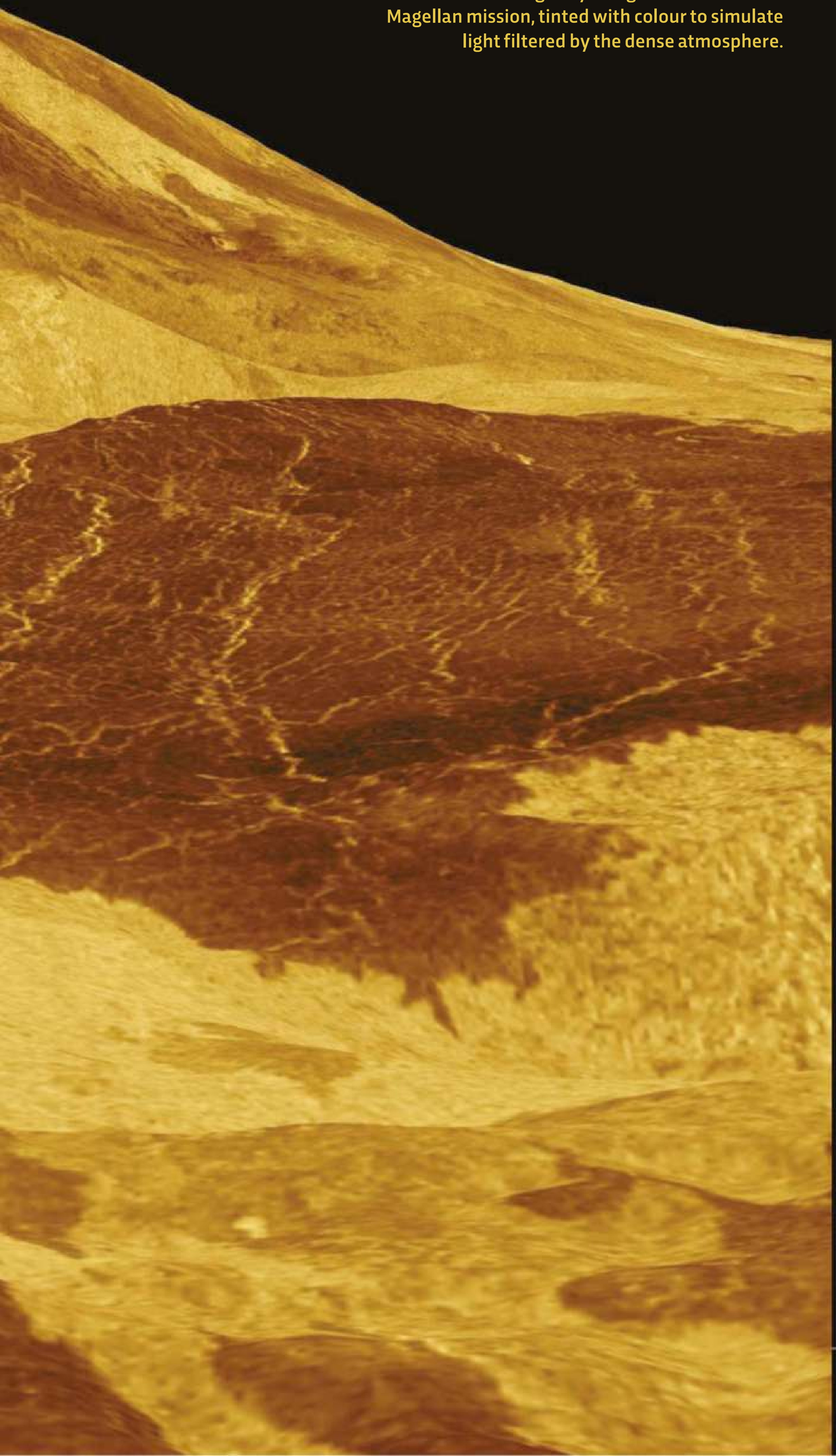
WORDS: **PAUL SUTHERLAND**

Despite being named after the Roman goddess of love, Venus is anything but romantic. Just 45 million kilometres from our planet's orbit, and with a mass 80 per cent that of the Earth's, it is our nearest neighbour in terms of both distance and size – yet our two worlds are vastly different.

Nothing was known about the surface of Venus before the Space Age, as it is completely obscured by thick clouds. Scientists once speculated that it might be a raging ocean, or a Sahara-like desert. The first probe to provide answers was NASA's Mariner 2, which flew past Venus in 1962, discovering that surface temperatures must be extremely high and that, like Uranus, it spins in the opposite direction to the rest of the planets in the Solar System. Since then, orbiting probes with cloud-piercing radar have produced maps of Venus's surface and Soviet landers have confirmed that conditions are completely inhospitable on the ground. There is neither sea nor desert, but rather a landscape resembling a vision of hell.

The surface temperature is twice the maximum found in a kitchen oven, reaching a roasting 462°C. The pressure of the atmosphere is





## SUPERVOLCANO

The largest volcano on Venus (also its second-highest mountain), Maat Mons is 8,000m high and has spewed lava – the dark patches in the foreground – that flowed for hundreds of kilometres from the volcano's base. This 3D view was created digitally using data from NASA's Magellan mission, tinted with colour to simulate light filtered by the dense atmosphere.

NASA

90 times that at sea level on Earth, crushing probes making early landing attempts. And it's also highly toxic, composed of 96 per cent carbon dioxide.

The first Soviet probe to reach the surface and send back signals was Venera 7 in 1970, but it was only able to survive in the harsh conditions down there for 23 minutes. It was followed by the more successful Venera 8 in 1972, which returned data on the surface temperature and pressure, wind speed and illumination, before being destroyed after 63 minutes. The probes had to be built like submersibles to withstand the air pressure, but their electronics quickly failed in the extreme heat. Subsequent Soviet landers in the 1970s and 1980s sent back crude photos of a rocky landscape.

Helium balloons were released into Venus's higher, cooler atmosphere in June 1985 by two Soviet Vega probes that were on their way to Halley's Comet. They gathered data for 47 hours each as they floated 50km high in the cooler clouds.

**MORE VISITS, MORE DISCOVERIES**

NASA's Mariner 10 flew past Venus in 1974 en route to Mercury and managed to image wind patterns in the clouds. This was followed by a dedicated US mission, Pioneer Venus, made up of two spacecraft that arrived in December 1978. An orbiter studied the atmosphere and made radar maps of the surface. The other component was a multi-probe made up of a transporter and four separate probes that were fired into the atmosphere, returning data for an hour.

NASA's next mission, Magellan, carried out extensive radar imaging of Venus from a polar orbit in the early 1990s. Its imaging revealed a planet covered with volcanoes. Scientists suspect many of them are still active, but still no one can say for certain.

The first envoy sent by the European Space Agency (ESA), Venus Express, was launched in November 2005. During its eight-year mission, the spacecraft's swooping orbit brought it low over the cloud tops and revealed big variations in the sulphur dioxide content, suggesting that the volcanoes were still active. Its fuel exhausted, Venus Express was purposefully destroyed in the atmosphere in early 2015.

A Japanese space probe called Akatsuki, launched towards Venus in 2010, looked lost after a fault caused it to fly past the planet. But five years later, mission controllers managed to rescue it and put it into a new, more elongated orbit where it began to survey the atmosphere.

Two NASA missions to the outer planets also gathered data on Venus as they flew by to get a gravitational boost on their long journeys. Galileo shot past on its way to Jupiter in February 1990, taking pictures, measuring dust, charged particles and magnetism, and making infrared studies of the lower atmosphere. Saturn probe Cassini made two flybys in April 1998 and June 1999 when it looked for, but failed to spot, lightning in the clouds.

### THE TROUBLE WITH LANDERS

Current proposals for future Venus missions are focusing on orbiters and a new generation of balloons and aerial vehicles. Experts see too many difficulties in sending a lander to explore the surface like the Martian rovers.

Two proposals to explore Venus are on a shortlist of five Solar System projects currently being considered for the next round of NASA's Discovery Program, missions that could launch in the early 2020s. One, called DAVINCI (Deep Atmosphere Venus Investigation of Noble gases, Chemistry and Imaging) is being studied by NASA's Goddard Space Flight Center. It is an entry probe designed to study conditions between the dense cloud tops and the surface.

The other proposal, from NASA's Jet Propulsion Laboratory, is for a new orbiter called VERITAS (Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy) that aims to produce radar maps of the planet in much higher resolution than before. It has strong European support and includes an infrared camera, built by a collaboration of French and German engineers, that will look for hot volcanic material on the surface.

Another attempt to get a new spacecraft to Venus will come from a UK-led proposal to ESA for a mission called EnVision. This will be an orbiter equipped with an advanced radar system capable of detecting tiny changes in surface features, and could confirm the presence of lava flows or similar surface deformations.

DAVINCI is intended to study conditions between the dense cloud tops and the surface

**Current proposals for future Venus missions are focusing on orbiters and a new generation of balloons**

Listen to an episode of *In Our Time* about Venus bbc.in/2SZKcxI

**Paul Sutherland** is a space journalist and the author of *Where Did Pluto Go?*

Looking farther ahead, Venus scientists are keen to see a new generation of balloons or airships to sample the planet's atmosphere. It has been suggested that simple microbial life might exist in the cloud tops, though this is pure speculation.

One advanced concept being prepared in the US is for a delta-winged aircraft called VAMP (the Venus Atmospheric Maneuverable Platform) to be dropped by an orbiter into the clouds. Once in the atmosphere it would switch to flight phase, spending up to a year manoeuvring between the upper and mid cloud layers, gathering data to send back to Earth. During the Venusian day, it would fly in the higher atmosphere, charging its batteries from the sunlight, before dipping to lower regions again at night.

With all these missions on the horizon, Venus may soon reveal more of its secrets.

NASA

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# EARTH

While the rest of the Solar System is populated by worlds of extremes, the Earth maintains a perfect balance

Earth is not too close to the Sun to boil, and yet not too far away that its water freezes, staying at just the right temperature to preserve the oceans that have helped shape our world. Indeed, our liquid water has been preserved for over four billion years, thanks to the atmosphere and magnetic field that protect us from harsh solar winds.

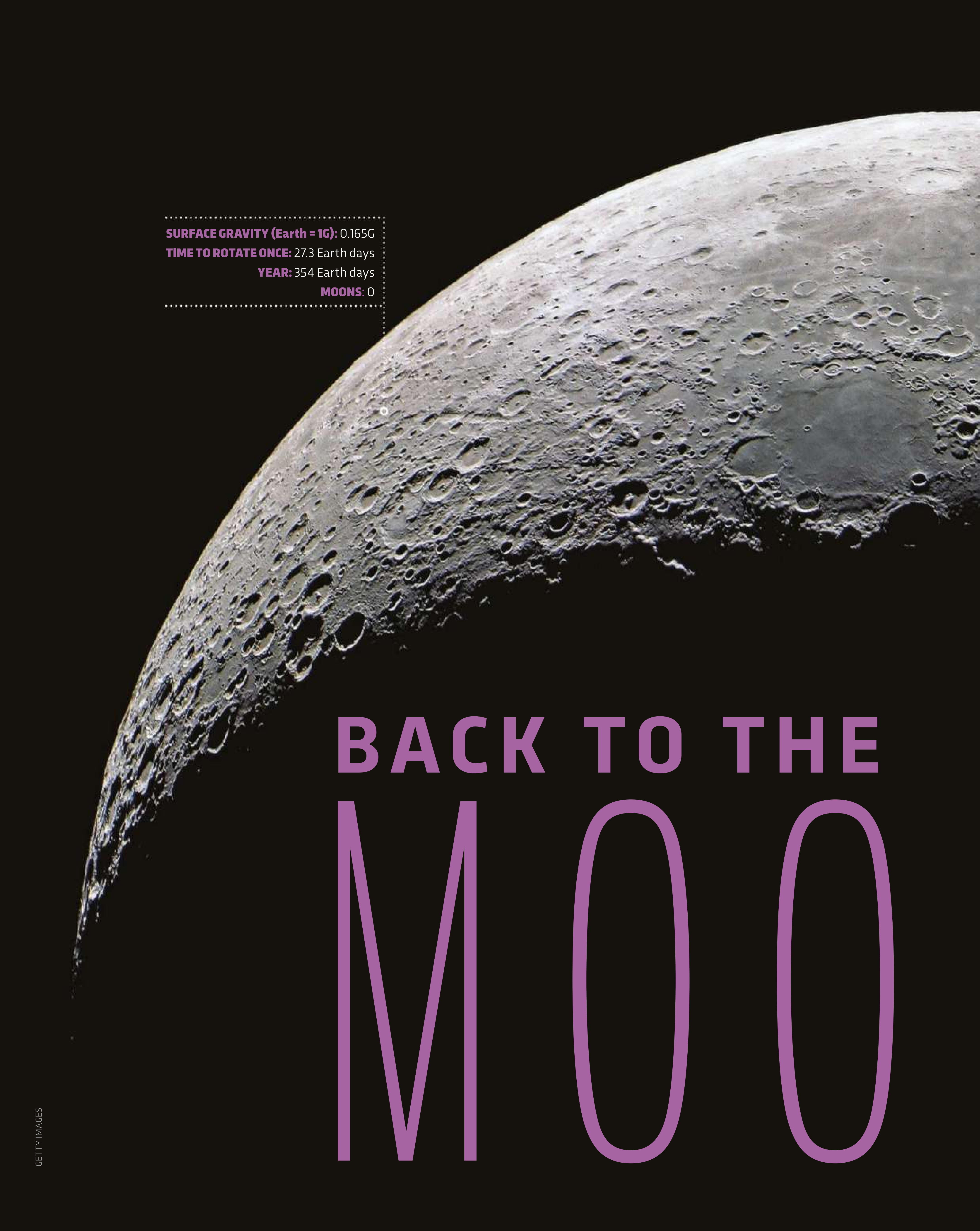
Occasionally, highly charged electrons from the solar wind manage to sneak through the magnetosphere around Earth's poles, smashing into atoms of oxygen and nitrogen in the atmosphere. The altitude at which they collide dictates the colours seen in the magical displays of the aurorae borealis (northern lights) and aurorae australis (southern lights).

The northern lights (aurorae borealis) seen over Norway

**TIME TO ROTATE ONCE:** 23.9 hours
**YEAR:** 365.26 days
**MOONS**: 1
**AVERAGE TEMPERATURE:** 16°C

## THE MOON

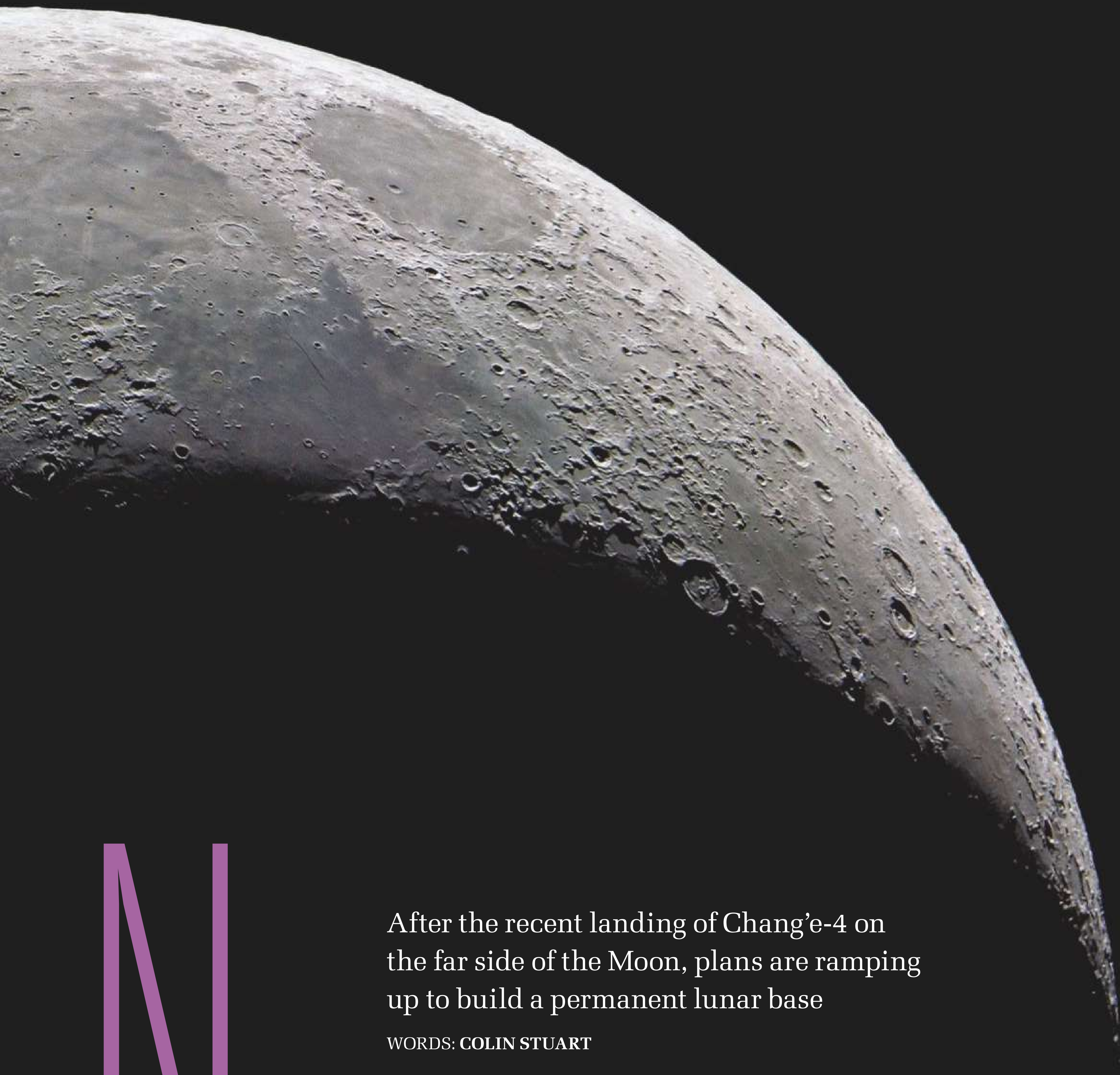
The prevailing theory for how the Moon formed is that there was a colossal crash between a Mars-sized planetoid and the proto-Earth. The Moon is the largest natural satellite in the Solar System relative to its planet's size. The two bodies have a huge effect on each other. The Moon's pull on our oceans creates the tides, and our planet's pull has gradually reduced the Moon's momentum so that its rotation is locked – which is why we only ever see the near-side of our lunar neighbour.



**SURFACE GRAVITY (Earth = 1G):** 0.165G
**TIME TO ROTATE ONCE:** 27.3 Earth days
**YEAR:** 354 Earth days
**MOONS:** 0

# BACK TO THE MOO

GETTY IMAGES



# N

After the recent landing of Chang'e-4 on the far side of the Moon, plans are ramping up to build a permanent lunar base

WORDS: **COLIN STUART**

"Now, let's get off. Forget the camera." These ordinary words have an extraordinary significance: they are thought to be the last words spoken by a human being on the Moon. That was in December 1972, when the departing Apollo 17 mission brought down the curtain on three years of audacious manned exploration during which 12 people left their footprints in the lunar dust. But for the past four decades our nearest neighbour has been without human contact, explored only by the robotic probes and rovers we've

Robotic construction equipment could be used to help build human habitats on the Moon

## CHINA'S MOON MISSION

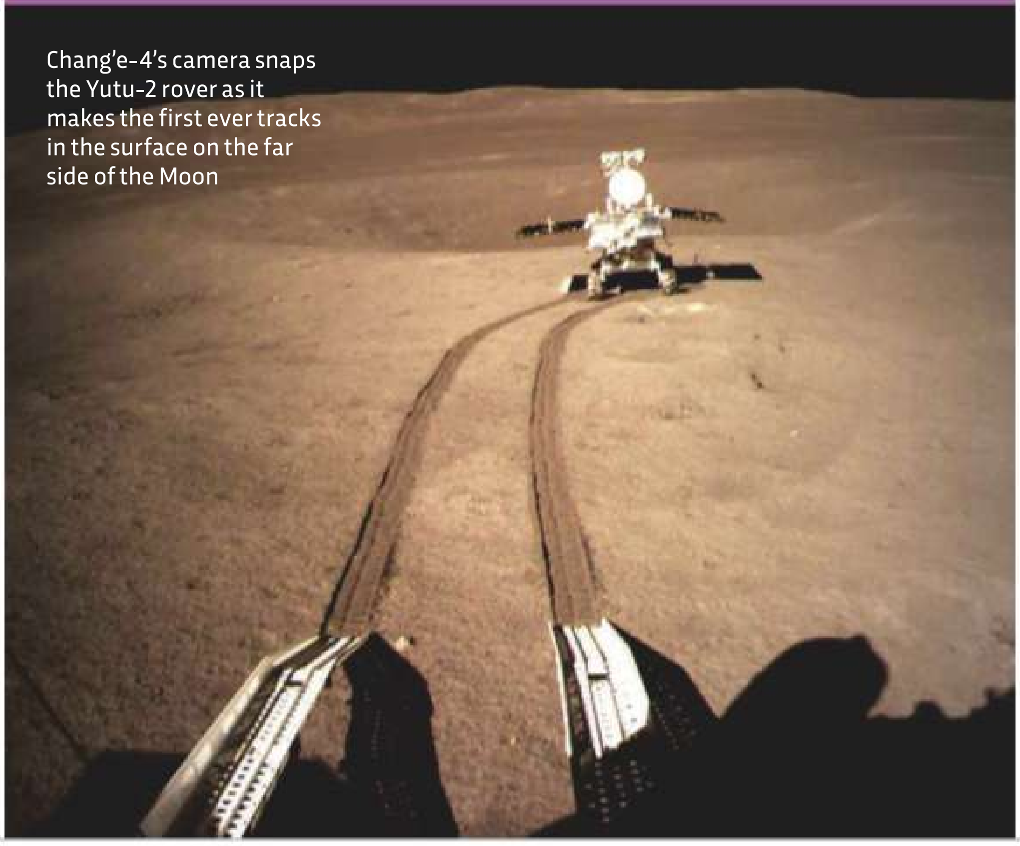
*After landing in early 2019, China's Chang'e-4 probe, carrying the Yutu-2 rover, became the first instrument to explore the surface on the far side of the Moon*

On 3 January, the Chinese Space Agency landed Chang'e-4 in the 180km-wide Von Kármán crater, which lies in the South Pole-Aitken basin, a huge crater on the far side of the Moon. Von Kármán was flooded with lava during the Moon's early days, meaning the crater floor is very smooth and safer to land on than elsewhere on the far side. But the impact that formed the Aitken basin could have broken through into the Moon's mantle, exposing deeper basalt material onto the lunar surface.

Analysing the composition of the far side of the Moon could provide valuable information about the substances available there. The Moon is thought to contain significant amounts of helium-3, which is rare on Earth but could be useful as a fuel. Other valuable chemicals and minerals could be hidden in these unexplored rocks, making them ideal for mining.

But geological exploration is far from the only mission aim. Numerous other experimental instruments are also crammed into the Chang'e-4 lander, such as an instrument capable of listening to faint astronomical radio signals. However, the majority of Chang'e-4's non-geological experiments are designed to investigate the possibility of future human missions to the Moon. For example, ASAN will study how the solar wind interacts with the lunar surface and the LND experiment will assess the strength of radiation in the Chang'e-4 vicinity.

Yet the experiment that's captured the most attention is the Lunar Micro Ecosystem. Inside a sealed 18cm-long container are fruit fly eggs and various seeds, one of which sprouted briefly before dying. Its aim is to study the possibility of farming crops in microgravity environments.



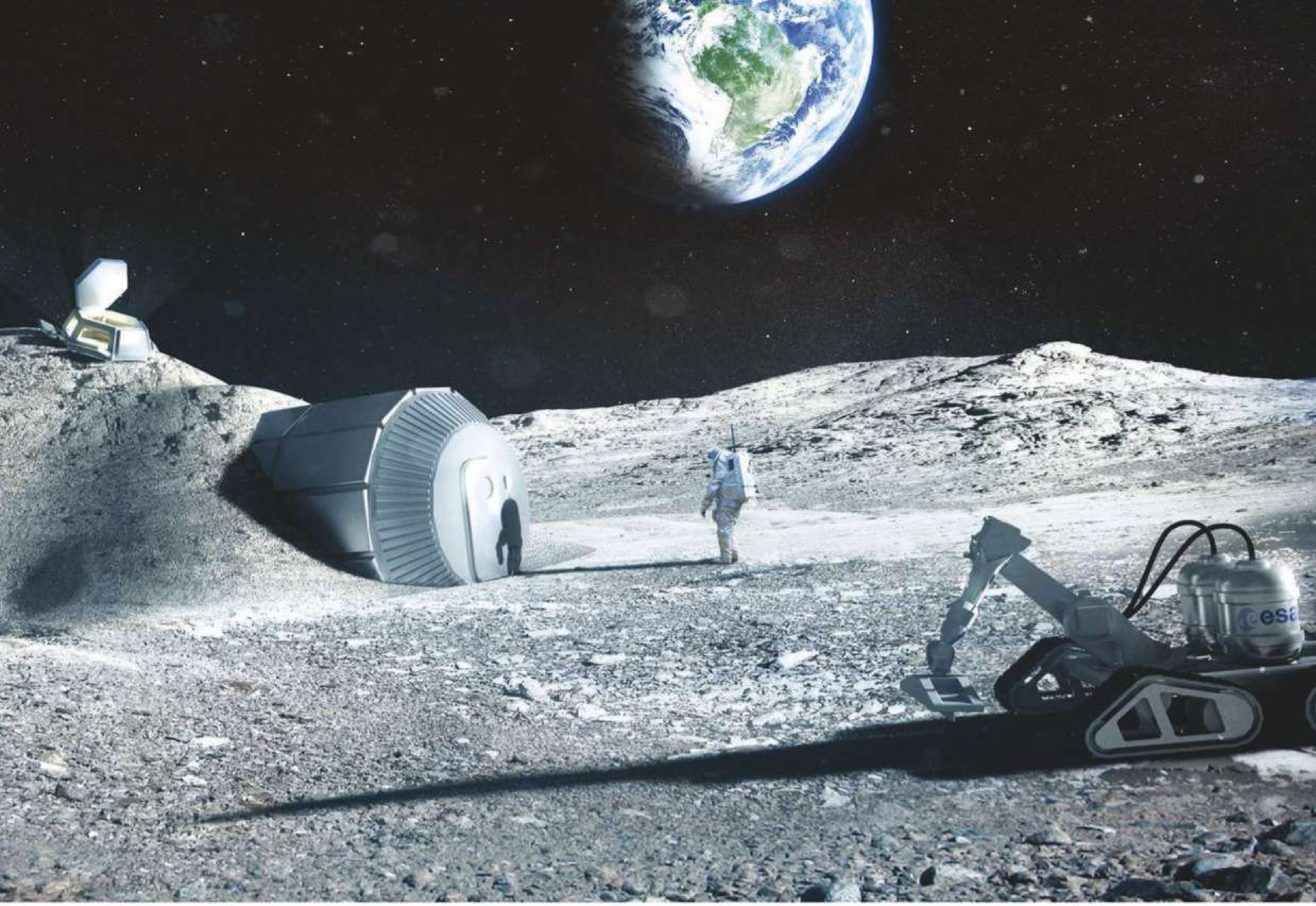
Chang'e-4's camera snaps the Yutu-2 rover as it makes the first ever tracks in the surface on the far side of the Moon

dispatched. But that may be about to change, at least if Johann-Dietrich Wöerner, the director general of the European Space Agency (ESA), gets his way – he wants to build a village on the Moon. Other space agencies around the world, including NASA, the China National Space Administration and the Russian agency, Roscosmos, have been making similar proposals. So could we finally be about to enter the era of a permanent human presence on the Moon?

### BLAST OFF

First things first: going to the Moon is expensive – it costs at least $10,000 (£7,670) to launch just 1kg of material into space. So the less you take with you the better. "The big buzzword at the moment is 'in situ resource utilisation' or ISRU," says University of Westminster astrobiologist Prof Lewis Dartnell. In other words, use what's already there as much as possible to keep the costs down. Therefore, local resources will govern where the base should be located.

SHUTTERSTOCK, ESO




## It costs $10,000 (£7,670) to launch just 1kg of material into space. So the less you take with you the better

Wöerner's idea is to start building on the far side of the Moon – the face that always points away from Earth. China also thinks this would be the best location. Hence, the recent Chang'e-4 mission to suss out the terrain (see 'China's Moon Mission', opposite). It would certainly be a good place to install telescopes, as it's sheltered from the all the background electromagnetic radiation produced on Earth. The downside is that you'd need a system of relay satellites in order to maintain contact with any base sited there – a key psychological factor for anyone manning the base so as not to feel too cut off. Plus, if you're thinking purely in terms of resources, then close to the south pole of the Moon might be a better bet for an initial dwelling as there's plenty of water ice there as well as other minerals. The Russians are currently looking into the feasibility of a base at Malapert Mountain in this region.

The other upside to the south pole is the climate. The Moon is a very different place to the Earth, taking nearly a month to complete one rotation on its axis. So on most parts of the Moon, periods of day and night both last around two weeks. But some regions of the Moon's south pole are almost always illuminated, much like our North Pole in summer. Any solar panels set up there would be able to soak up plenty of sunlight and could be used to provide a near-constant supply of power for a lunar colony.

If at first a manned lunar colony seems like too much of a risk, we might start with a robot-only base. That's certainly the plan

LEFT: Apollo 12 astronaut Charles Conrad uses the lunar hand tool to pick up samples of Moon rock during the 1969 NASA mission

that JAXA, the Japan Aersopace Exploration Agency, has in the pipeline. It hopes to have a permanent robotic base on the Moon by 2020, with machines gathering lunar samples from up to 97km away before returning to their HQ and blasting their hauls back to Earth via rockets.

**WHAT WE CAN LEARN**

The scientific attraction is clear. The lunar samples returned to Earth by the Apollo astronauts have been an invaluable resource for increasing our understanding of the inner workings and history of our celestial companion. Yet that knowledge is still limited, as only a small amount of material was returned from a few lunar locations. A team of robots would improve our knowledge – but better yet would be a group of permanent dwellers, which would send our ability to study the Moon into overdrive.

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# HOW TO MAKE A MOON BASE

*The advent of 3D printing could be a game-changer for building a lunar village*

At the end of 2014, the design for a socket wrench was emailed to astronauts on the International Space Station, who then used their 3D printer to create it. Researchers are excited by the prospect of using a similar technique for bases on the Moon.

The European Space Agency (ESA) is already in consultation with architects Foster + Partners about the possibility of creating a large-scale infrastructure on the Moon by 3D printing it using lunar soil, known as regolith.

Bigelow Aerospace has proposed a slightly different construction method, using a small, standalone inflatable pod. The company is already cooperating with NASA in the hope that their first inflatable Moon base will be in place by 2025.

The Russian plan to colonise Malapert Mountain is also being led by a private company – Lin Industrial. It believes the technology required for such a feat isn't available now, but predicts it will be in as little as five years. A total of 50 rocket launches would make the base a reality, but at a cost of nearly $10bn (£7.6bn).

1. First the 3D printer scoops up the regolith.
2. Next, it mixes the regolith with magnesium oxide to form a printable material.
3. Then the 3D printing head builds up the structure, layer by layer on the 'scaffold' formed by an inflatable dome.
4. The material can then be 'set' by binding it with salt to create a solid material.

"A good comparison is how a permanent human infrastructure in Antarctica has facilitated scientific research that wouldn't have happened if we just parachuted in automatic payloads from time-to-time," explains Prof Ian Crawford, a planetary scientist from Birkbeck, the University of London.

> **Lunar habitation could extend our knowledge of areas beyond the Solar System**

Interestingly, lunar habitation could extend our knowledge of areas beyond the Solar System – the Moon has long been regarded as an excellent place to build telescopes to peer out into the distant cosmos. Optical telescopes would have an unprecedented view of the Milky Way and radio telescopes would be free from the electromagnetic hum of modern civilisation. Humans could be sent to build and service these instruments, much as they do with the mountain-top telescopes on Earth.

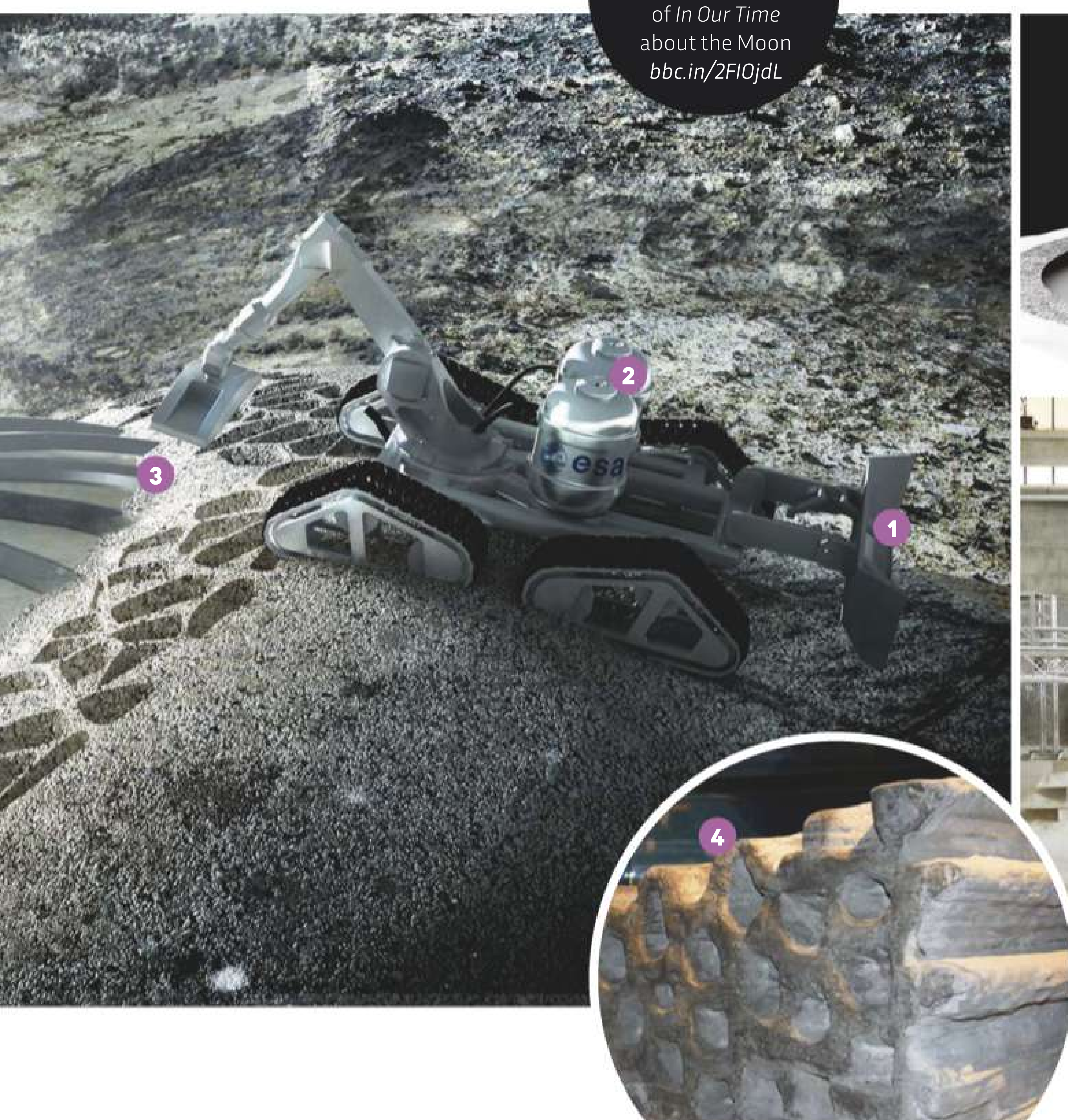
But the first Moon base may not be funded by government-led space agencies at all – private enterprise could be first to set up shop. A recent NASA study suggested that a public-private partnership could slash the cost of the mission by 90 per cent.

With eyes also on a permanent Mars colony, the Moon would be an excellent place to test out nascent technologies. It's certainly a lot safer – if things go wrong it only takes a few days to return to Earth. Alternatively, emergency supplies could be quickly couriered to the lunar surface. An outpost on Mars would be far more remote, leaving anyone in a colony there at least six months from help.

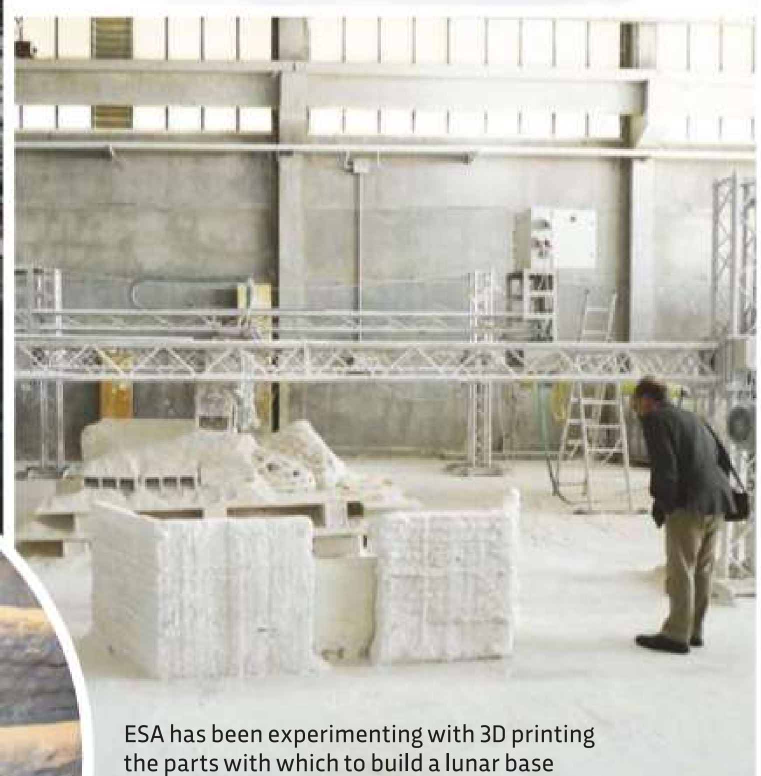
**Colin Stuart** (@skyponderer) is a space author. His latest book is *How to Live in Space.*

BBC RADIO 4

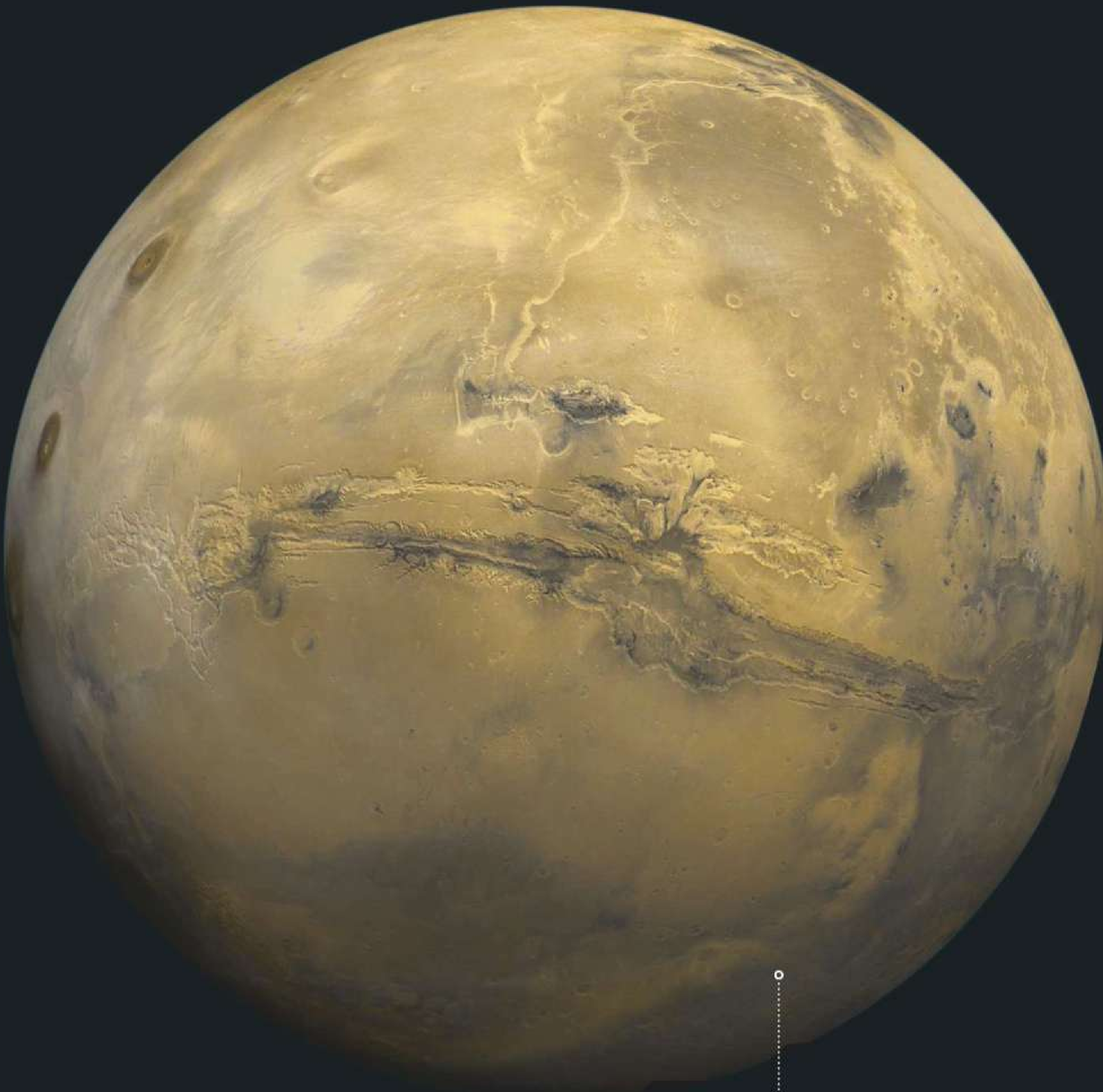
Listen to an episode of *In Our Time* about the Moon *bbc.in/2FIOjdL*




The pressurised inflatable living area could house four people



ESA has been experimenting with 3D printing the parts with which to build a lunar base



SURFACE GRAVITY (Earth = 1G): 0.38G
TIME TO ROTATE ONCE: 24.6 hours
YEAR: 687 Earth days
MOONS: 2

# MARS

With a diameter half that of Earth, Mars is the Solar System's second smallest planet, but is probably the one that has most captured the human imagination. Until Mariner 4 sent back the first close-up images of Mars in the 1960s, many believed it might harbour life

## OPHIR CHASMA

Ophir Chasma forms the northern-most edge of Mars's enormous Valles Marneris canyon complex, a scar that runs 5,000km (3,100 miles) across the Red Planet's equator (see left). All of the dimensions associated with this geological formation are staggering: Ophir Chasma alone is around 100km (62 miles) wide and the tallest cliffs bordering it stand 5,000m high, making it almost three times as deep as America's Grand Canyon. NASA's Viking 1 orbiter captured this composite image of Ophir Chasma in 1976.

VIKING PROJECT/USGS/NASA, NASA/JPL/USGS

A few billion years ago, Mars probably didn't look that different from our own planet. Only another 75 million kilometres farther away from the Sun than Earth, it was warm enough to maintain liquid oceans on most of the surface and its short day of 24 hours and 40 minutes helped to keep the temperature constant across the planet's surface. Now, however, Mars is very different. At some point the planet was stripped of its atmosphere and, with it, most of the water. Though some remains frozen into the soil, the Martian surface is now a barren, dead landscape.

Neverthless, many believe that in its more pleasant days, Mars might once have been home to more than rocks and dust. Dozens of missions have been sent to the planet, hoping to find signs of life.

# OLYMPUS MONS

This image, captured by NASA's Viking 1 orbiter, shows the giant volcano Olympus Mons shrouded in cloud. The clouds – most likely composed of water-ice – sit a full 8km below the volcano's 26km-high peak. In comparison, Everest is only 8.8km high.

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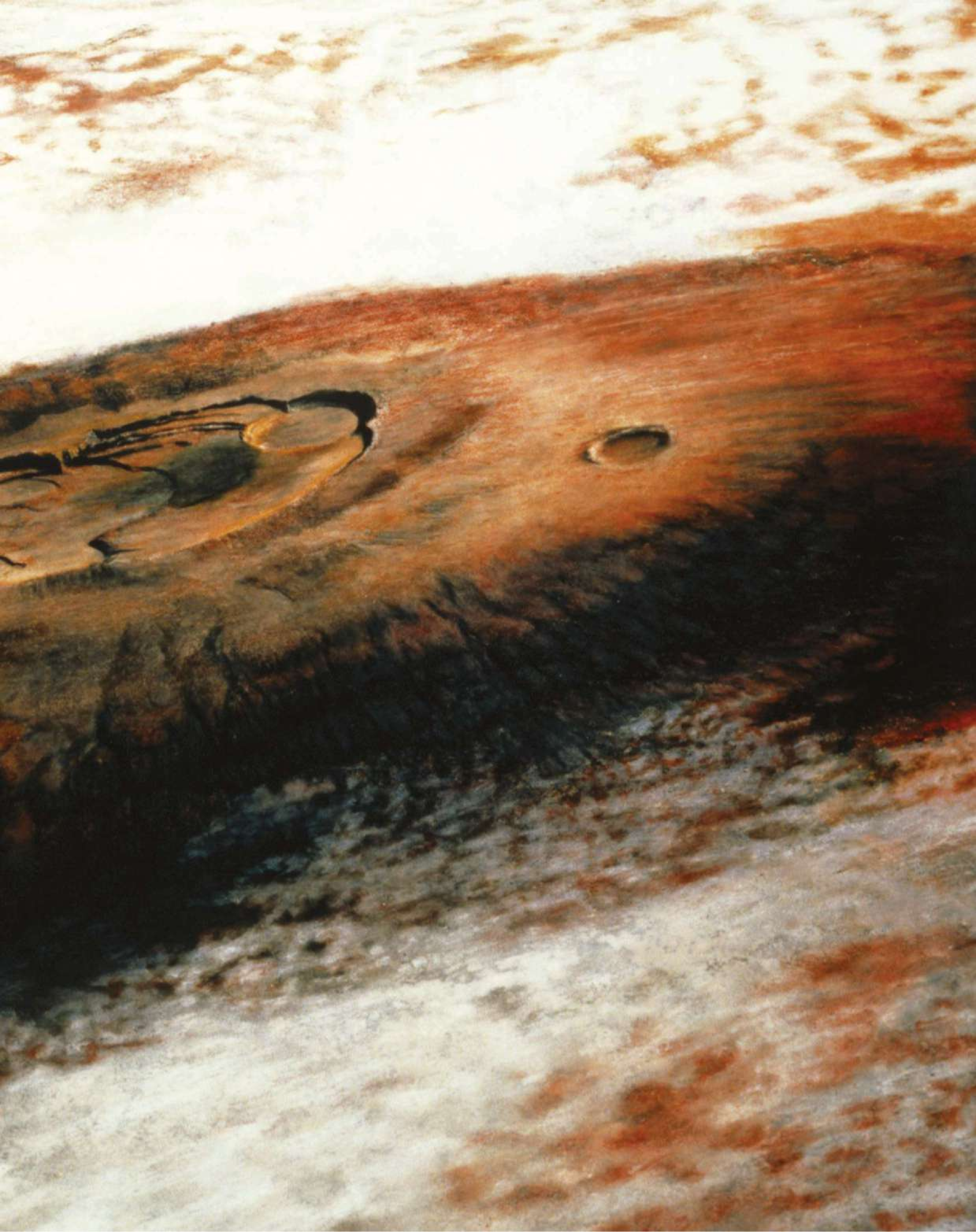


# INSIDE THE RED PLANET

Mars has been an object of intrigue for centuries, and an armada of orbiters and rovers have explored it up close. Yet for all our exploration efforts there remains a perplexing mystery: just what is going on deep within Mars?

WORDS: **COLIN STUART**

Previous missions to Mars have focused on what's happening on the surface. That's no surprise given the menu of marvels on offer: sweeping sand dunes, soaring volcanoes and scintillating blue sunsets. We now know Mars's surface so well that we have a better map of it than we do of the ocean floor on Earth. Yet it's the deepest layers of a planet that really make it tick and relatively little is known about the Red Planet's interior. But that is changing.

On 26 November 2018, NASA's InSight spacecraft touched down on the Martian surface, where it will spend a minimum of one Martian year (nearly two Earth years) surveying deep beneath the famously ruddy dirt.

The smooth plains of Elysium Planitia were chosen as the landing site because they ticked so many boxes. "First there were the engineering constraints," says Dr Suzanne Smrekar from NASA's Jet Propulsion Laboratory in California, the deputy principal investigator for the mission. The landing site had to be less than two kilometres above Martian 'sea level' so that the probe could travel through enough atmosphere to slow it down. Equally important for the purposes of a safe landing, the site needed to be a wide, open space free of large rocks and other potential obstacles. It also had to be close to the Martian equator so that the probe can get enough sunlight to stay powered for at least a Martian year (687 Earth days) – the minimum intended duration of the mission, Smrekar explains. She does, however, caution against expecting the stunning pictures of sweeping Martian landscapes that we've come to expect from missions like Spirit, Opportunity and Curiosity. And that's because InSight's mission scientists care about what's under the surface, not what's on it.

ANDY POTTS

The goal of InSight is to give Mars's interior the planetary equivalent of a full-body health check. It will take the planet's 'pulse' by monitoring seismic activity (known as 'Marsquakes') and record its temperature by keeping track of the heat flow under its surface. That will help us understand how rocky planets, such as Earth and Mars, formed in the first place. On Earth, most of these clues have been erased due to the action of our tectonic plates over billions of years. While seismic activity has been measured on the Moon, thanks to instruments left by the Apollo astronauts, it's a much smaller world and formed in a different way to the Solar System's four rocky planets. Mars could hold secrets about how Earth came to be in the first place and InSight hopes to find them. "Mars is the perfect place for us to learn about terrestrial planet formation," says Smrekar.

**Whatever we find will be interesting and exciting, as so little is known about what's going on down there**

**TESTING, TESTING**

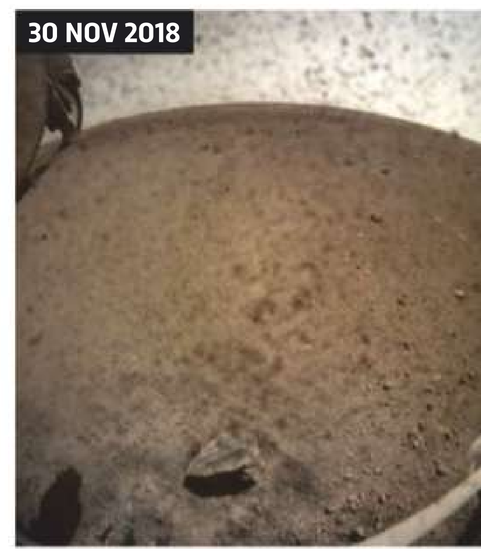
One of InSight's key instruments is a seismometer (known as SEIS) for measuring tremors from deep within Mars. For Dr Neil Bowles, from the University of Oxford, it's the most exciting part of the mission. The thing he's most looking forward to is "the first unequivocal detection of a Marsquake". One of the Viking landers of the 1970s carried a seismometer, but it wasn't in direct contact with the Martian surface. According to Bowles, that meant any tremors were felt through the legs of the lander and were therefore hard to measure accurately. It was better suited for sensing the fearsome Martian winds, but not for picking up underground vibrations. InSight's seismometer, however, is in direct contact with the ground and covered with a thermal shield to protect it from both the Martian wind and temperatures. It's so sensitive that it can pick up vibrations smaller than the width of a hydrogen atom. That's more than enough to also detect the tell-tale thump of meteorite impacts on the Martian terrain.

The first full seismic data from SEIS is starting to trickle back to Earth. "Whatever we find will be interesting and exciting, as so little is known about what's going on down there," says Bowles.

It's been over 130 years since similar measurements were made of earthquakes here on Earth and our knowledge about our planet's innards has been transforming ever since. "From the way vibrations are reflected and refracted inside the Earth, we've learned about its inner structure," Bowles says. Without ever travelling into our planet, we know that it has a solid iron inner core encased in a liquid outer core, which sits beneath the mantle and crust. InSight may bring the same level of knowledge about Mars, and in doing so shed light on one of Mars's greatest mysteries: what happened to its magnetic field.

Earth's magnetic field is generated by the movement of material in the liquid outer core as the planet spins. There's evidence that Mars once had a global magnetic field too, but now all that remains are scattered patches of localised magnetism. It could be that, as Mars is a smaller planet, there wasn't enough material crushing down on the core to keep it liquid. If it solidified, there would no longer be movement, so the magnetic field would have switched off. Magnetic fields protect planets from the solar wind, which is a stream of charged particles blowing out from the Sun. Once Mars had no magnetic field, the solar wind was able to sweep away the planet's atmosphere.

It's hoped that InSight can use the way vibrations travel through Mars to determine whether any of its core is still liquid. Understanding the link between the core and Mars's magnetic field could prove crucial if we're to send astronauts to Mars and protect them from the harsh radiation generated by the Sun and the rest of the stars in the Milky Way.



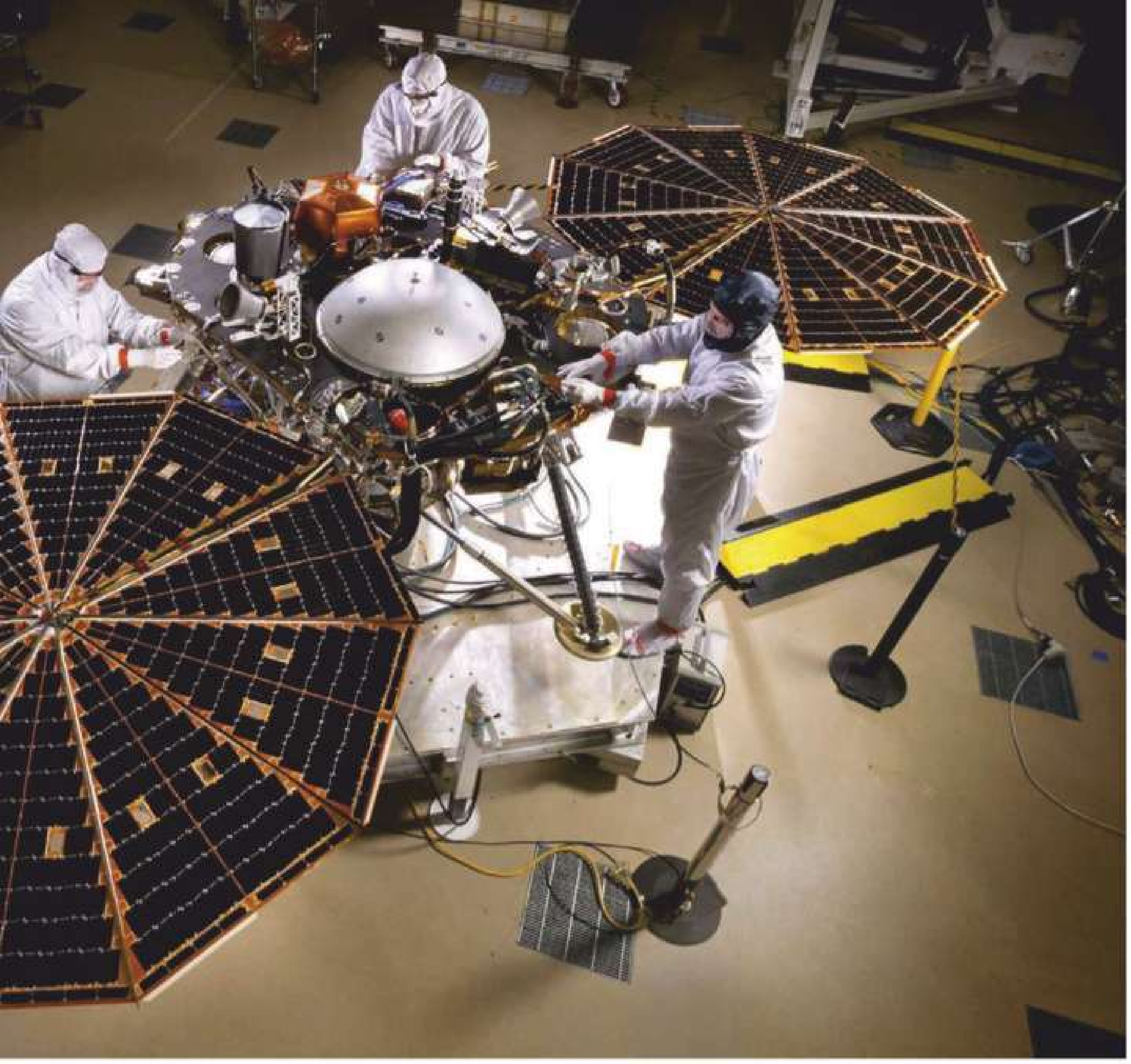

TOP: In a clean room on Earth, InSight's solar array is deployed for testing

ABOVE: The ICC (Instrument Context Camera) captured this view of Mars a few days after InSight landed

ABOVE MIDDLE: InSight's Instrument Deployment Camera captures an image of the orange, hexagonal SEIS (Seismic Experiment for Interior Structure) instrument and the black, cylindrical Heat Flow and Physical Properties Probe (HP3)

ABOVE RIGHT: An ICC photo of the SEIS instrument as it's gradually deployed on the Martian surface

NASA, NASA/JPL-CALTECH X3



4 DEC 2018

26 JAN 2019

InSight might also reveal sub-surface reservoirs of water, kept as a liquid by heat rising from the core. It might be the only place on Mars where its ancient water has been able to survive in liquid form. If life got started on Mars in its more temperate past, it may still be clinging on in these subterranean seas.

**HOT TOPIC**

If SEIS is the equivalent of a doctor's stethoscope, listening for the planet's heart, the Heat Flow and Physical Properties Probe (known as HP3) is like putting a thermometer under Mars's tongue. Smrekar describes it as "a self-hammering nail". The whole experiment weighs only 3kg and will send back just over 40 megabytes of data over the duration of the mission – around the same as a low-quality YouTube video. Like a mole, it will burrow into the Martian soil to a depth of five metres – far deeper than any Mars probe before it. According to Smrekar, that's deep enough to get away from any surface temperature variations due to day and night or Mars's swinging seasons. Every 50cm, the probe will emit a heat pulse and measure how that pulse dissipates through the Martian sub-surface. The quicker it fades, the better the surrounding material is at conducting heat – a sure-fire way to figure out what it's made of.

HP3 is also on the hunt for evidence of heat generated by radioactive decay. Elements such as uranium, thorium and potassium spontaneously break down over long periods into lighter elements, releasing energy along the way. It's thought Mars and Earth formed in a similar fashion from "planetary building blocks crashing together and melting," says Smrekar. If the two planets formed from the same material, then we should expect a similar heat signature as those materials undergo radioactive decay. "InSight will tell us if the heat coming out of Mars is consistent with that picture," says Smrekar.

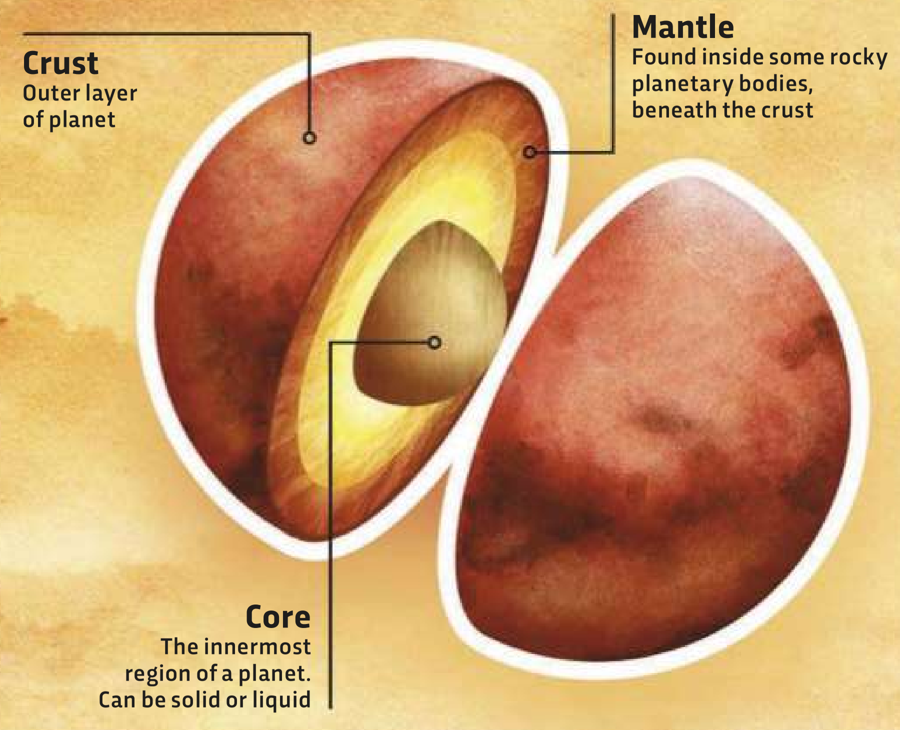
That leaves the Rotation and Interior Structure Experiment (RISE), which measures the medical equivalent of the planet's reflexes. As Mars orbits the Sun, it wobbles on its axis much like Earth. Exactly how it wobbles depends on what's going on in the centre of Mars. You can test this for yourself by comparing how a raw egg spins compared to a hard-boiled one. A partially liquid Martian core would lead to a different wobble compared with a solid core. So measurements from RISE will complement those from SEIS in order to shed light on why Mars's magnetic field shut off. The instrument will accurately track InSight's position as Mars spins on its axis by reflecting a radio signal sent from Earth back home. Any wobbles on Mars's axis will be evident through tell-tale shifts in the frequency of the signal, in a similar way to how the pitch of an ambulance siren changes as it hurtles past you.

If all goes to plan, we'll finally get crucial information about the most unexplored part of the most explored planet in the Solar System.

**Colin Stuart** is an astronomy speaker and author. His latest book is *How To Live In Space*. He tweets from @skyponderer.

# THE INSIGHT MISSION

- Mars's distance from Earth varies between **54.6 million km** and **401 million km**
- There are rocks on Mars named after cartoon characters including **Scooby-Doo** and **Yogi Bear**
- **Ice on Mars sublimates** rather than melts – it goes straight from ice to vapour, skipping the liquid phase
- In the past, Mars likely had **liquid oceans** covering at least one-fifth of its surface
- **38%** – The surface gravity on Mars compared to what we experience on Earth




### 1 SEIS
This instrument for measuring Marsquakes is sensitive enough to pick up tiny vibrations the size of a hydrogen atom.

### 2 WTS
The Wind and Thermal Shield will help protect the SEIS instrument while it's exposed to the Martian surface conditions.

### 3 SOLAR PANELS
Based on the design of the Phoenix lander, these should provide enough power to last a Martian year.

### 4 TETHERS
Cables through which data and commands can be exchanged between the deployed experiments and main body of the lander.

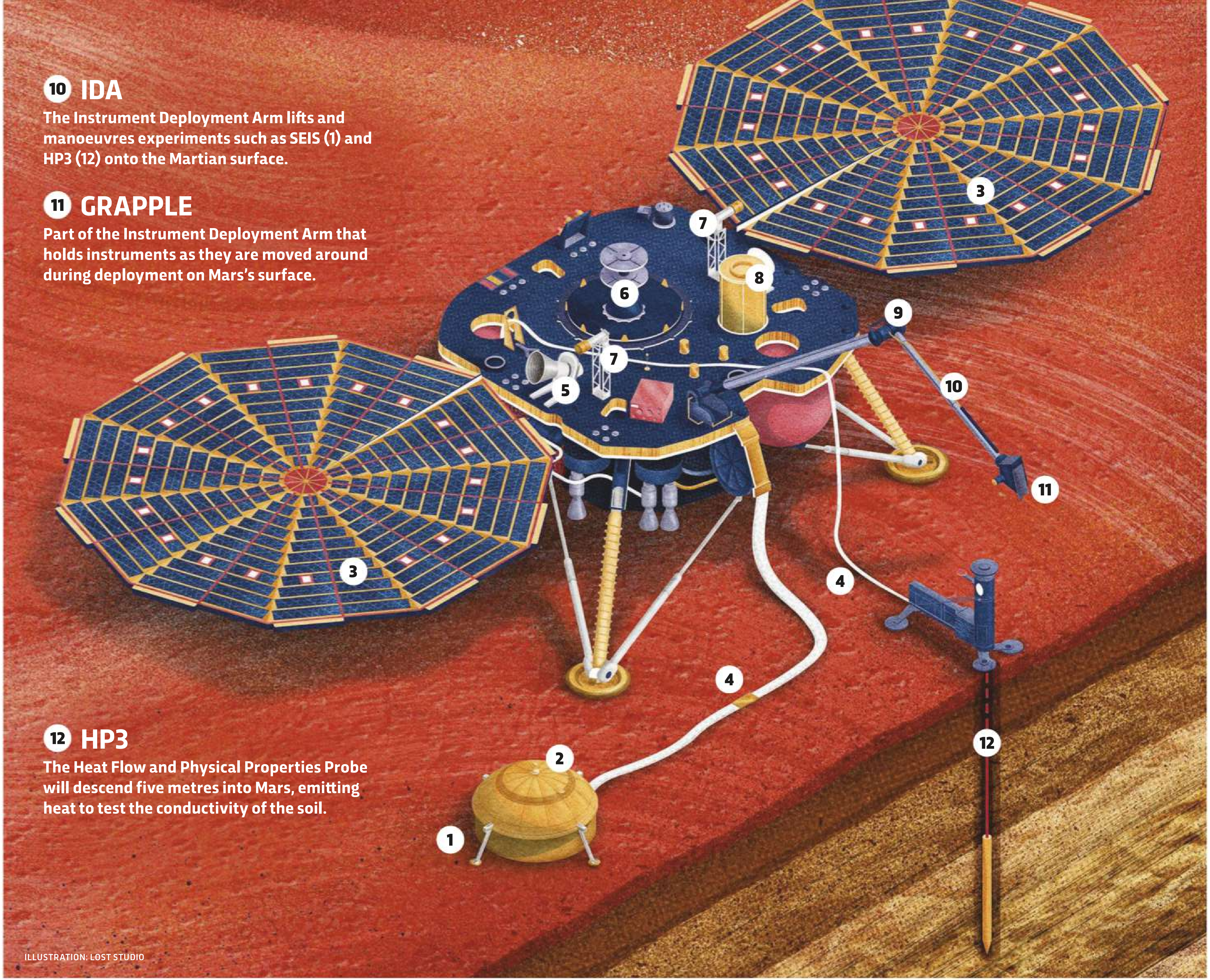
### 5 RISE
The Rotation and Interior Structure Experiment measures the probe's position and Mars's wobble to reveal the planet's inner structure.

### 6 PRESSURE INLET
This wind-shielded opening allows the lander to make measurements of Mars's atmospheric pressure conditions.

### 7 TWINS
This stands for Temperature and Winds for InSight – essentially they're weather stations for monitoring prevailing atmospheric conditions.

### 8 UHF ANTENNA
Ultra-high frequency antenna that allows communication between InSight and orbiting spacecraft that can relay data back to Earth.

### 9 IDC
This is the probe's Instrument Deployment Camera, which will aid mission scientists in moving the other experiments around.




## 10 IDA

The Instrument Deployment Arm lifts and manoeuvres experiments such as SEIS (1) and HP3 (12) onto the Martian surface.

## 11 GRAPPLE

Part of the Instrument Deployment Arm that holds instruments as they are moved around during deployment on Mars's surface.

## 12 HP3

The Heat Flow and Physical Properties Probe will descend five metres into Mars, emitting heat to test the conductivity of the soil.

ILLUSTRATION: LOST STUDIO

# HUMANS ON MARS

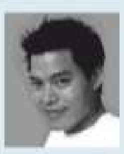
We've been dreaming of setting foot on the Red Planet for decades. At last, NASA and private company Mars One have begun preparations for a manned mission, but huge obstacles stand in the way. Some of the world's leading experts on long-term space missions reveal how we'll finally set foot on Mars…

## EXPERTS

**Prof Suzanne Bell** works on NASA's Human Research Program

**Prof Mason Peck** is the former Chief Technologist at NASA

**Prof Charles Cockell** is the director of the UK Centre for Astrobiology



**Dr Kevin Fong** has worked with NASA and is the author of *Extreme Medicine*

BBC TWO

Watch a *Horizon* clip of *Mars: A Traveller's Guide* *bbc.in/2syn918*

### WHAT KIND OF PERSON WOULD BE PICKED FOR A MARS MISSION?

**Prof Suzanne Bell:** Working and living in such an extreme environment will require capable individuals who are intelligent, fit, adaptable and stable, with great teamwork skills. When the team is faced with a situation that presents competing priorities (for instance, whether to lose data or preserve equipment), they will more easily agree on a course of action if they have shared values.

There is a level of social warmth typically associated with extroverted individuals, but the isolation and social monotony of space requires a certain level of introversion. 'Ambiverted' individuals have qualities of both introversion and extroversion. But even the most carefully selected, emotionally stable person is likely to struggle with the extreme isolation at some point, so will need to be trained in coping skills.

Plus, going to Mars is a risk, but you don't want someone who is too much of a risk-taker. Living and working in a hostile environment means that one small mistake could have major consequences; it could even mean the death of the team. So the right person will be able to be careful and responsible in their actions, yet still have a great sense of adventure.

### HOW WOULD WE SEND A CREW TO MARS?

**Prof Mason Peck:** The four-person crew will travel to the Red Planet in a transit vehicle – a small space station that will be assembled in low Earth orbit before the crew arrives. In-orbit assembly allows us to build large space systems, like the International Space Station (ISS), that we're unable to launch intact from Earth, for technical or financial reasons.

Once the crew is onboard, the transit vehicle will fire its engines and begin its journey to Mars. This will be the astronauts' home for seven months, and they'll eat, sleep and train in the vehicle's habitat module. Then, when they're near Mars, they'll enter a separate lander module, a bit like the Apollo landers.

The four-person crew will be carried to the orbiting transit vehicle by a system such as SpaceX's Falcon Heavy. It'll be a similar approach to the way astronauts travel to the ISS today.

We'll continue sending four-person crews to Mars at every launch opportunity – roughly every 26 months, when Mars and Earth align in a way that minimises the propellant needed for the trip.

### HOW WILL WE LAND ON MARS?

**Prof Mason Peck:** Landing won't be easy. NASA's analysis predicts that a six-person mission would need to land 40,000kg on the Martian surface. The largest payload delivered to date is just 1,000kg (the Mars Science Lab mission, which landed the Curiosity rover in 2012).

One possibility is aerocapture – slowing the vehicle down by sending it through the Martian atmosphere. This would create a drag force, reducing the craft's orbital energy. Secondly, inflatable aerodynamic decelerators might be used. Currently in development, these expand to create a large, lightweight, heat-resistant body that further slows the vehicle.

Some rocket companies are also looking into landing vehicles through retropropulsion – the

GETTY IMAGES


## *"The aspect of Martian life that will shape physiology most of all is the reduced gravity"*

ABOVE: Crews will have a busy first few days on Mars, setting up habitats and the necessary equipment to support their presence

Buck Rogers technique of firing rocket engines in front of you to slow yourself down.

### WHAT WILL THE FIRST FEW DAYS ON MARS BE LIKE?

**Prof Charles Cockell:** The first few days will be a Lego-like frenzy of putting together the Martian base. Colonists will need to ensure that radiation shielding is in place, and oxygen production and recycling equipment is working. If they're topping up their oxygen from water gathered from the atmosphere (by breaking it down using electrolysis), they'll need to check that the extractor fans collecting atmospheric water are up and running.

In the first weeks, colonists will eat dried and preserved rations, but they will spend time setting up a simple greenhouse so that they can begin to grow food as soon as possible.

A crucial matter for survival is energy. Whether they're using nuclear or solar energy, they'll need to set up the apparatus, link it to the base and make sure that the power supply is stable and reliable. They may also set up chemical apparatus to make things like fuel. Carbon dioxide in the atmosphere, for instance, can be reacted over a catalyst with hydrogen (itself released from water gathered from permafrost or the atmosphere) to make methane fuel to power their robotic rover.

### WHAT WOULD HAPPEN TO THE HUMAN BODY AFTER A YEAR ON MARS?

**Dr Kevin Fong:** Mars doesn't support life any better than empty space. It's smaller than Earth and further from the Sun, with a thin atmosphere composed of carbon dioxide. When crews arrive there, they'll be completely dependent upon a suite of life support systems and forced to live in habitats that are shielded from radiation. But the aspect of Martian life that will shape physiology most of all is the reduced gravity – it's roughly one-third of the gravity on Earth.

More than 50 years of human space flight has shown that weightlessness has effects on the human body. Bone and muscles waste rapidly and the heart, which is itself a muscle, deconditions. But other systems are also affected. Hand-eye coordination becomes impaired, the immune system becomes suppressed and astronauts can become anaemic. Prolonged weightlessness can take athletes and turn them into couch potatoes very quickly.

Crews will rely on a combination of drugs, controlled diet and strict exercise regimes to ward off the deconditioning effects. Though some authorities have proposed the use of short-arm centrifuges to provide a short burst of artificial gravity at the surface.

# GREAT RED SPOT

If you were to compose a list of the seven wonders of the Solar System, Jupiter's Great Red Spot would be near the top. This gigantic storm system is bigger than planet Earth, and rotates in an anticlockwise direction with a period of about six days. Although a large circular storm has been reported on Jupiter from the 1660s onwards, it may not be the one we see today. Records are poor between 1713 and 1831 and may indicate that the original storm dissipated, and that the Great Red Spot we see today 'only' formed in the 19th Century. This image is an artistic endeavour based on real data. Citizen scientist Gerald Eichstädt used data from the JunoCam instrument and enhanced the colour to draw the eye into the storm. The raw image was taken on 10 July 2017, during Juno's seventh close flyby of the planet. When the image was taken, the craft was about 10,000km (6,200 miles) above the planet's cloud tops.

NASA/JPL-CALTECH/SWRI/MSSS/GERALD EICHSTADT

SURFACE GRAVITY (Earth = 1G): 2.5G
TIME TO ROTATE ONCE: 9.9 hours
YEAR: 12 Earth years
MOONS: 79

# JUPITER

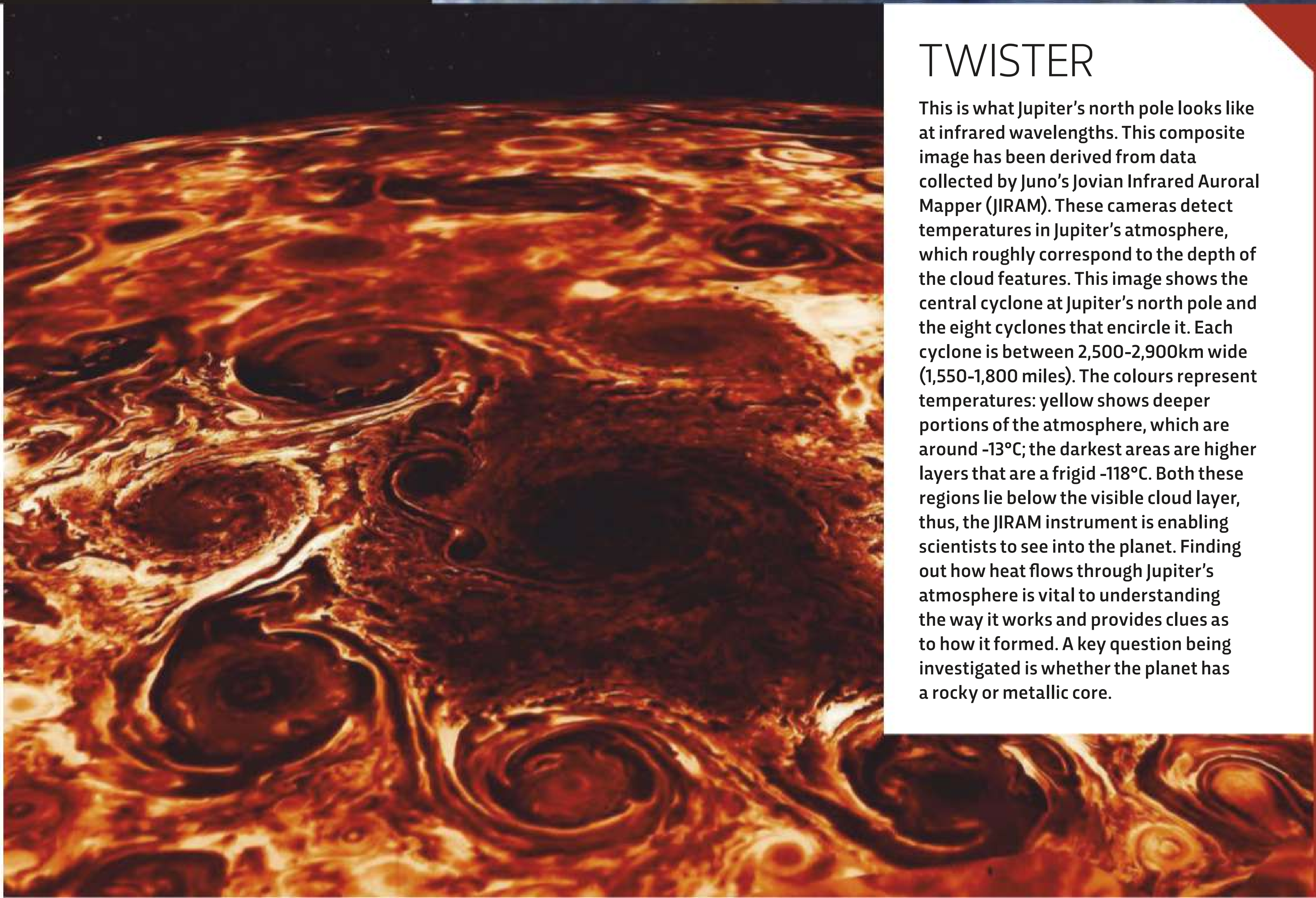
**NASA's Juno spacecraft began photographing Jupiter in 2016. The images it's captured so far have transformed our understanding of the biggest planet in our Solar System**

WORDS: **STUART CLARK**

In classical mythology, the god Jupiter surrounded himself in clouds to keep his antics hidden from view. Only his wife, Juno, could see through the veil to his true nature. And so it is with the NASA spacecraft of the same name. The secrets of the formation of the whole Solar System lie below Jupiter's all-encompassing clouds, just waiting to be discovered. Theories about our Solar System's formation all begin with the collapse of a giant cloud of gas and dust, otherwise known as a nebula, the majority of which formed the Sun. Like the Sun, Jupiter is mostly hydrogen and helium, so it too must have formed early on, capturing most of the leftover material after our star formed. How this happened, however, is unclear. Did a massive planetary core form first and gravitationally capture all that gas, or did an unstable region collapse inside the nebula, triggering the planet's formation? Juno's instruments are starting to give researchers insights on how the planet formed and what the conditions in the early Solar System were like. But the craft also carries an instrument called JunoCam, which has taken a raft of spectacular images...

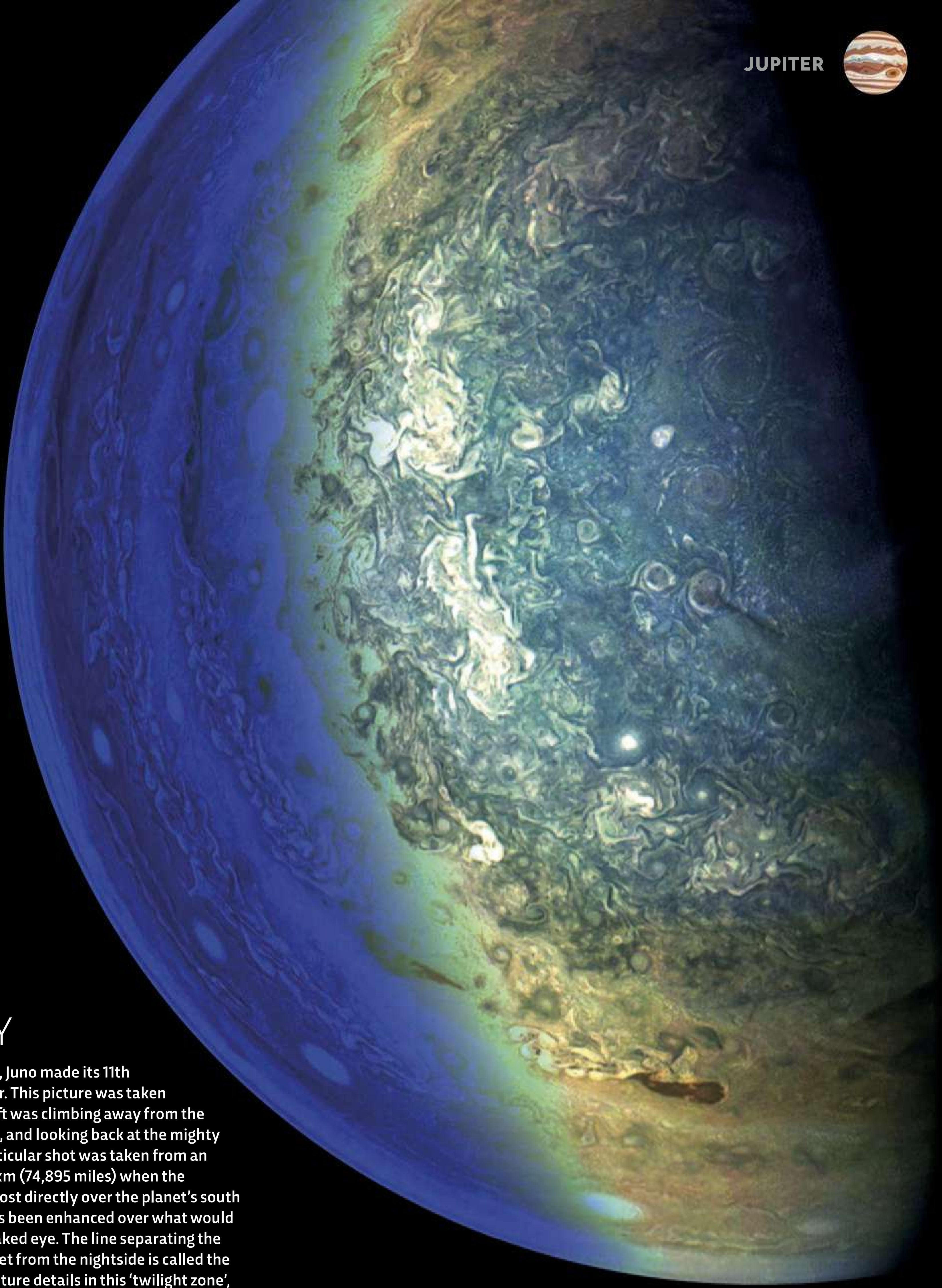
## CLOUDS OF ICE

This raging storm in Jupiter's northern hemisphere was captured during Juno's ninth close flyby on 24 October 2017. The image was taken with the JunoCam instrument and processed by citizen scientists Gerald Eichstädt and Seán Doran to enhance the colours and bring out the details in the clouds. The storm is rotating anticlockwise. The brighter clouds are higher in the atmosphere and catching more light, whereas the darker clouds are deeper down and so more shadowy. In this image, the sunlight is coming from the left-hand side of the image. Both the bright clouds and their shadows measure from 7-12km (4.5-7.5 miles) in length and breadth. They appear to be similar to other bright clouds seen by Juno, so are probably highly reflective due to ammonia ice crystals that are borne upwards on rising currents of gas from deeper within Jupiter's atmosphere. They may also be mixed with crystals of water ice. Juno took this image from a distance of 10,108km (6,280 miles).



## TWISTER

This is what Jupiter's north pole looks like at infrared wavelengths. This composite image has been derived from data collected by Juno's Jovian Infrared Auroral Mapper (JIRAM). These cameras detect temperatures in Jupiter's atmosphere, which roughly correspond to the depth of the cloud features. This image shows the central cyclone at Jupiter's north pole and the eight cyclones that encircle it. Each cyclone is between 2,500-2,900km wide (1,550-1,800 miles). The colours represent temperatures: yellow shows deeper portions of the atmosphere, which are around -13°C; the darkest areas are higher layers that are a frigid -118°C. Both these regions lie below the visible cloud layer, thus, the JIRAM instrument is enabling scientists to see into the planet. Finding out how heat flows through Jupiter's atmosphere is vital to understanding the way it works and provides clues as to how it formed. A key question being investigated is whether the planet has a rocky or metallic core.



NASA/JPL-CALTECH/SWRI/MSSS/GERALD EICHSTADT X2, NASA/JPL-CALTECH/SWRI/MSSS/GERALD EICHSTADT/SEAN DORAN

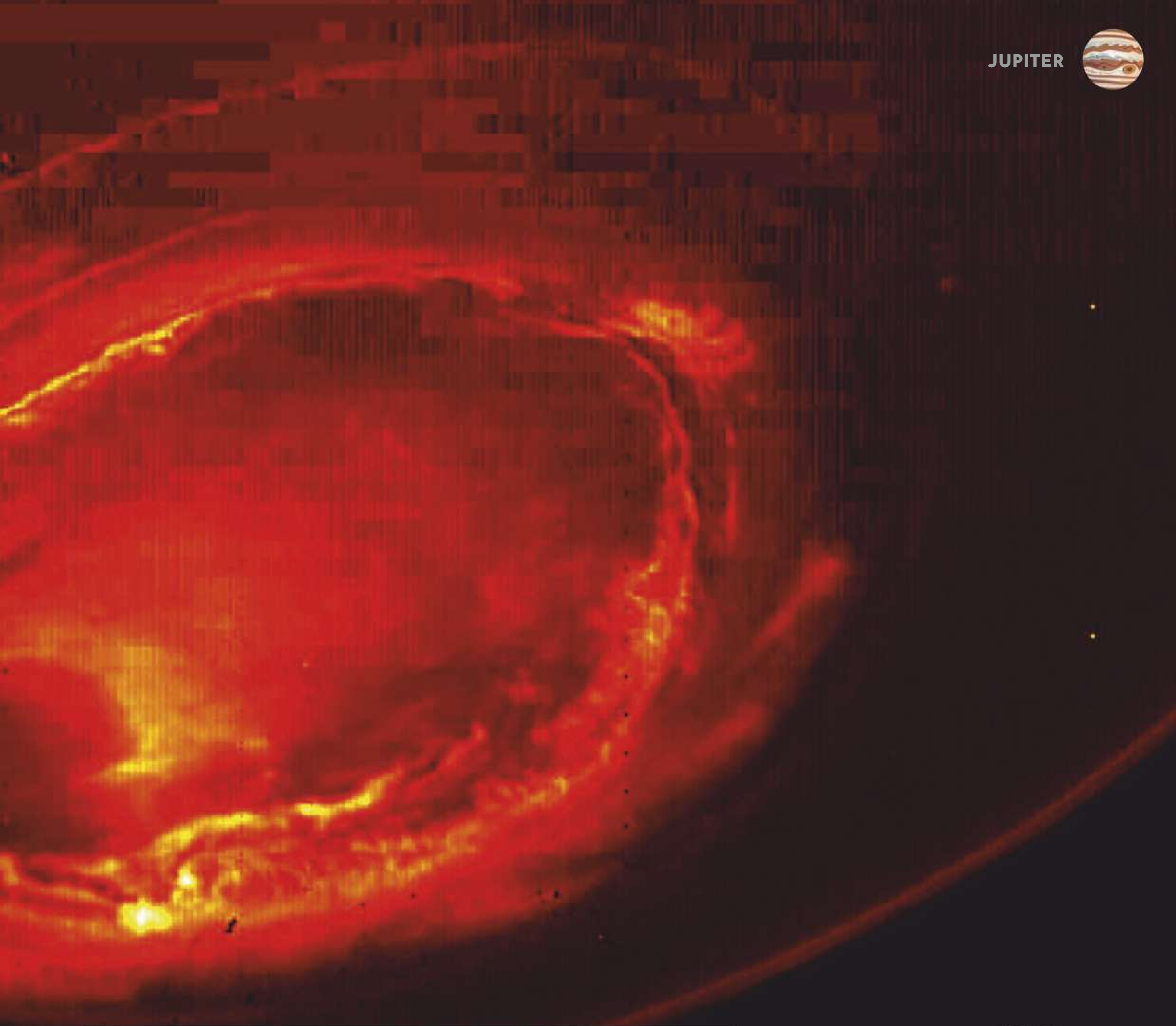
# NIGHT AND DAY

**On 7 February 2018, Juno made its 11th close pass of Jupiter. This picture was taken when the spacecraft was climbing away from the planet's south pole, and looking back at the mighty gas world. This particular shot was taken from an altitude of 120,533km (74,895 miles) when the spacecraft was almost directly over the planet's south pole. The colour has been enhanced over what would be seen with the naked eye. The line separating the dayside of the planet from the nightside is called the 'terminator'. To capture details in this 'twilight zone', when day is turning to night and vice-versa, the JunoCam instrument took a number of different images with different exposure times. The longer exposures showed the details of the twilight zone but overexposed the daylight side of the planet. The shorter exposures captured the bright hemisphere but failed to show anything near the terminator. Computer processing by citizen scientist Gerald Eichstädt then merged the two images.**

# EYES OF THE STORM

Although the Great Red Spot grabs the glory when we think about Jupiter's giant storms, it's just one of many that rage in the planet's atmosphere. This image shows two white storms. It was taken by the JunoCam instrument from an altitude of 33,115km (20,577 miles) during the ninth flyby of Jupiter on 24 October 2017, and was processed by Gerald Eichstädt and Seán Doran. The image is more colourful than our eyes would see because it has been enhanced to bring out the details in the atmosphere. The storm at the bottom of the image is part of Jupiter's 'String of Pearls'. This is a series of oval storms, all of them white in colour, that encircle the planet's southern hemisphere at a latitude of 40°. Since 1986, the number of storms has varied from six to nine. There are currently eight of these storms, all rotating in an anticlockwise direction. These vast storms are being powered by heat generated in Jupiter's interior.

NASA/JPL-CALTECH/SWRI/MSSS/GERALD EICHSTADT /SEAN DORAN, NASA/JPL



# ALIEN AURORA

This infrared image gives an unprecedented view of the southern aurora of Jupiter. The view is a mosaic of three images taken minutes apart as Juno was pulling away from Jupiter, after its first close approach. From Earth, the planet's southern aurora can hardly be seen. It was captured by Juno's Jovian Infrared Auroral Mapper (JIRAM) on 27 August 2016. Auroras are ovals of light that occur when particles from the Sun strike molecules in a planet's atmosphere and cause them to glow. The auroras appear as ovals because the magnetic field of the planet corrals the solar particles into a cone-shaped funnel that feeds them into the atmosphere around the planet's magnetic poles. The same occurs on Earth, but as Jupiter's magnetic field is the strongest planetary field in the Solar System – fully 20,000 times stronger than Earth's – its auroras are stronger. This image is composed of wavelengths longer than visible light, ranging from 3.3 to 3.6 micrometres (one micrometre = one-thousandth of a millimetre). These wavelengths were chosen because they're emitted by excited hydrogen ions. These are atoms that have lost an electron particle and dominate the planet's atmosphere.

BBC TWO

Watch an episode of *Horizon* about Jupiter *bbc.in/2LWI0aQ*

**Dr Stuart Clark** is an astronomy writer with a PhD in astrophysics. His latest book is *The Unknown Universe*.

# WHAT LIES BENEATH

## NASA is preparing for a new mission to search for signs of life below the surface of one of Jupiter's frozen moons

WORDS: **IAIN TODD**

As humanity's unmanned spacecraft traverse the Solar System, there is one key question that begs to be answered. Could it be that the rest of the Solar System is entirely barren, or is there some form of life that is thriving somewhere beyond Earth?

### SUBTERRANEAN OCEAN

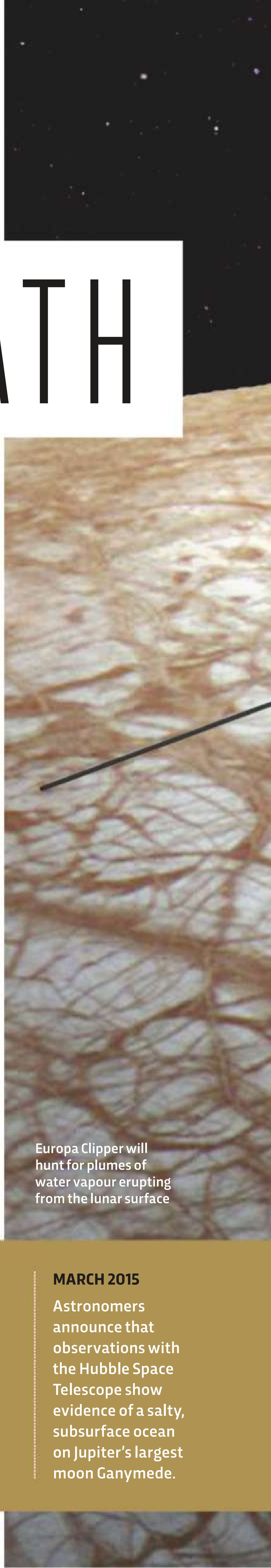
One of NASA's current projects is Europa Clipper. Due for launch in 2022, the spacecraft will fly into orbit around Europa, the smallest of Jupiter's four Galilean moons. This icy world is of particular interest to scientists because there is strong evidence of a salty ocean hidden beneath the planet's frozen surface. And water is a key ingredient for life as we know it.

Europa Clipper is one of many missions that will search for regions in our Solar System where even the smallest microbial life might have a chance of grasping hold. The study of so-called 'extremophiles' on Earth has revealed organisms that can survive in the harshest environments, from boiling hot or freezing cold temperatures to extreme pressures, high acidity and saturated salty solutions. Perhaps organisms such as these could inhabit a moon like Europa. It isn't a completely frozen world, after all. Its surface may be ice, but tidal flexing of the moon caused by its orbit around Jupiter could be enough to generate hydrothermal activity and maintain a liquid subsurface ocean.

The Clipper will perform 45 flybys of Europa, diving from 2,700km (1,680 miles) to just 25km (16 miles) above the surface, and is equipped with nine science instruments to collect data along the way. The spacecraft will search for any plumes bursting through Europa's frozen crust, as these could contain water vapour and might point to a subsurface ocean. It will then analyse the material, searching for potential water particles in its atmosphere and collecting data. Other data should also give scientists a detailed picture of Europa's magnetic field and gravitational pull, the thickness of its crust and the depth of its ocean.

If life does exist elsewhere, Europa is currently one of our best chances of finding it. On Earth we tend to see an abundance of life wherever water exists, so the prospect of a salty ocean hidden on an icy moon is too good to pass up. Subsequent missions may even be able to put a lander on Europa and explore the salty liquid below its surface. And, if scientists can find what they're looking for, it may be enough to at least partly answer the question as to whether we are alone in the Universe.

**Iain Todd** is a space journalist and staff writer at *BBC Sky at Night* magazine.



NASA/JPL

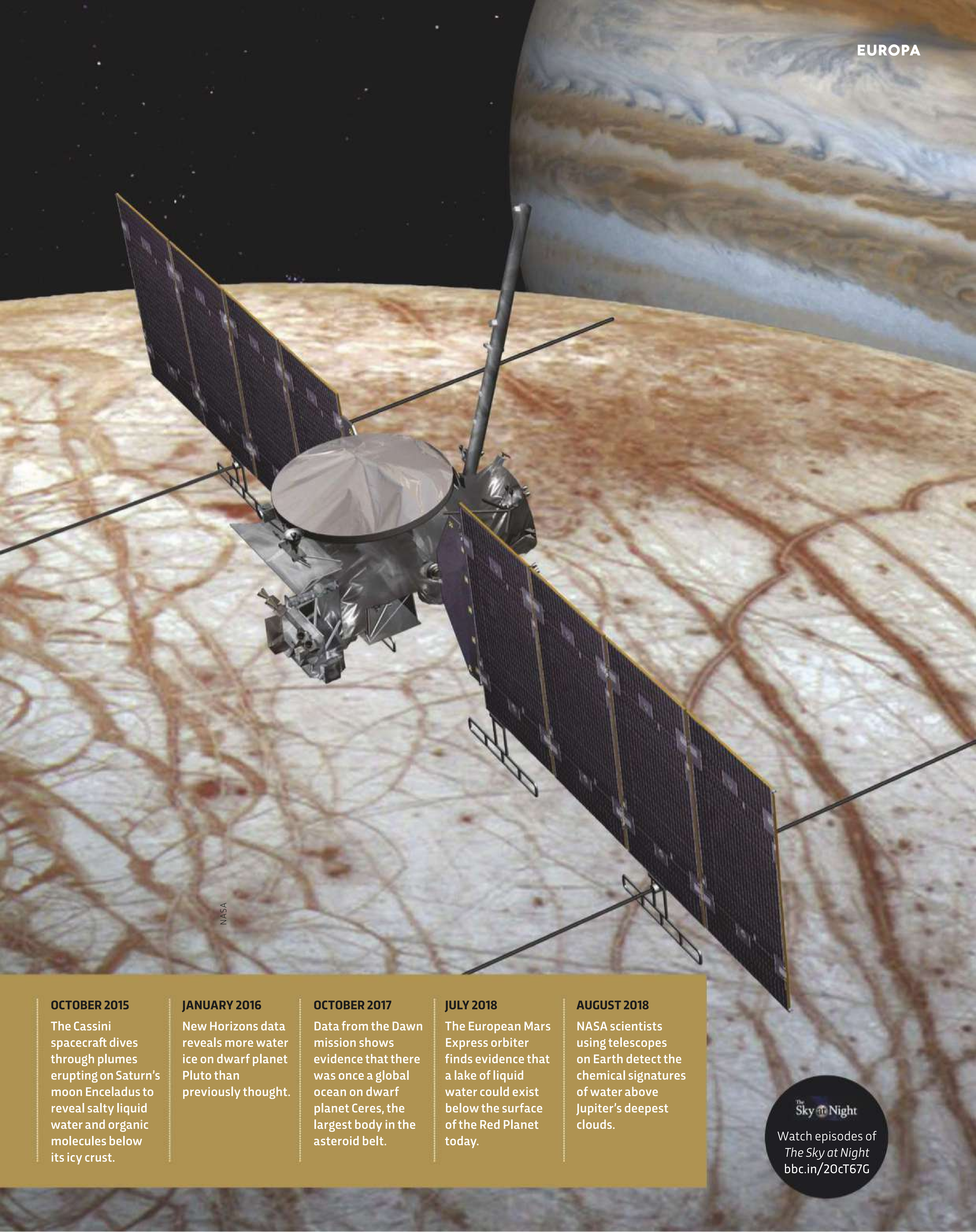
Europa Clipper will hunt for plumes of water vapour erupting from the lunar surface

## THE HUNT FOR $H_2O$

*Recent discoveries show that water may be found in many places in the Solar System, hinting at potentially suitable conditions for life, past and present*

**MARCH 2015**

**Astronomers announce that observations with the Hubble Space Telescope show evidence of a salty, subsurface ocean on Jupiter's largest moon Ganymede.**



NASA

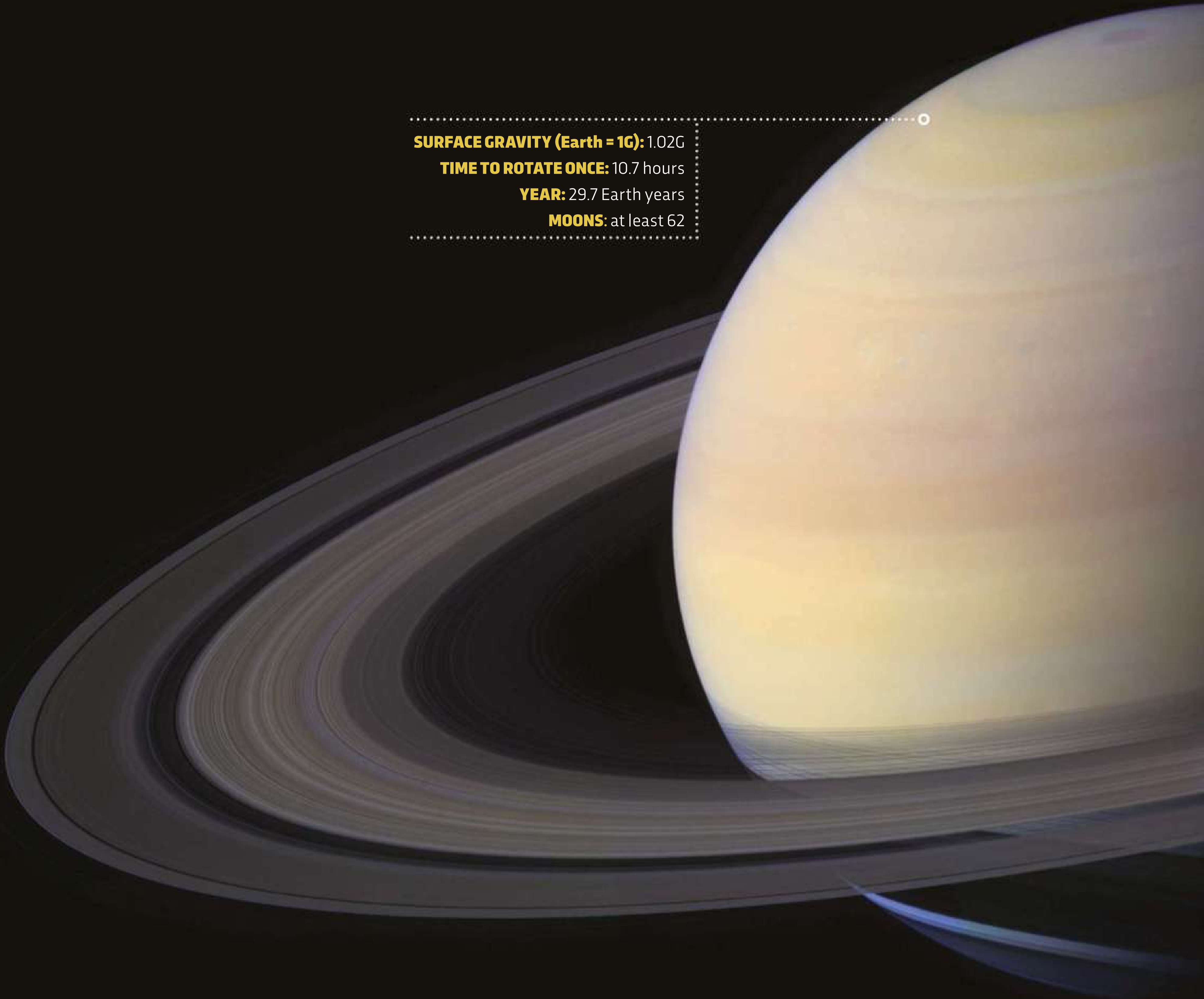
**OCTOBER 2015**
The Cassini spacecraft dives through plumes erupting on Saturn's moon Enceladus to reveal salty liquid water and organic molecules below its icy crust.

**JANUARY 2016**
New Horizons data reveals more water ice on dwarf planet Pluto than previously thought.

**OCTOBER 2017**
Data from the Dawn mission shows evidence that there was once a global ocean on dwarf planet Ceres, the largest body in the asteroid belt.

**JULY 2018**
The European Mars Express orbiter finds evidence that a lake of liquid water could exist below the surface of the Red Planet today.

**AUGUST 2018**
NASA scientists using telescopes on Earth detect the chemical signatures of water above Jupiter's deepest clouds.




# SATURN

The second largest planet in our Solar System is 760 times bigger than Earth. At 9.5 times farther away from the Sun, Saturn can be seen with the naked eye

WORDS: **WILL GATER**

Made almost entirely of hydrogen, Saturn is so light that – if you could find a swimming pool big enough to test the theory – the entire planet would float in water.

Saturn's most famous features are its rings. Almost pure water ice, the nine main rings extend to 80,000km above the surface of the planet that is itself 120,500km in diameter. Surprisingly, they are only 1km thick. The gravity of Saturn's 62 known moons helps to shepherd the ice into defined orbits, leading to the intricate patterning of the rings.

How exactly the rings were created is still a mystery. Some theories suggest that they comprise material left over from the planet's formation, others that they are the shattered remains of a moon. It's uncertain if the rings are even a permanent fixture or merely a passing feature that we are lucky enough to glimpse.

This high-resolution composite image was pieced together from 126 frames captured by NASA's Cassini spacecraft, and depicts the planet's southern hemisphere and rings

MATTIAS MALMER/CASSINI IMAGING TEAM

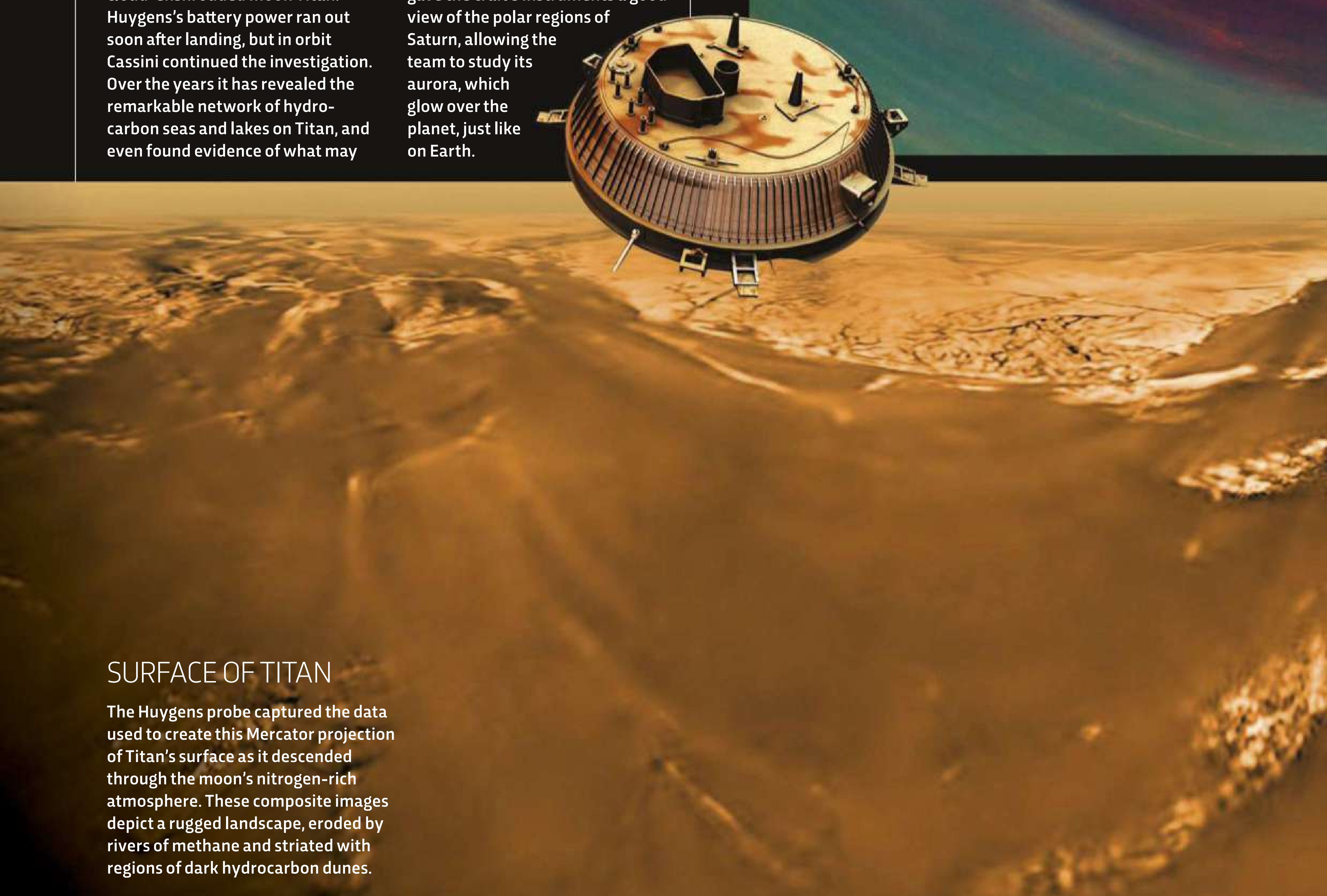
# CASSINI MISSION

*For over a decade, this NASA craft shared incredible images of Saturn and its moons, helping to solve many puzzles about these mysterious worlds*

Some of Cassini's most intriguing findings were from its encounters with the planet's moons. It captured images of plumes of icy particles being fired out from surface jets on the moon Enceladus, suggesting the presence of a subsurface ocean. And the Huygens probe revealed extraordinary pictures of the cloud-enshrouded moon Titan. Huygens's battery power ran out soon after landing, but in orbit Cassini continued the investigation. Over the years it has revealed the remarkable network of hydro-carbon seas and lakes on Titan, and even found evidence of what may be waves on some of the seas.

Cassini's 13-year-long reconnoitre of Saturn ended in September 2017 when NASA intentionally crashed it into the Saturnian cloud tops, ensuring any microbes were destroyed, so that these alien worlds would not be contaminated. But the final orbits gave the craft's instruments a good view of the polar regions of Saturn, allowing the team to study its aurora, which glow over the planet, just like on Earth.

NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE, ESA/NASA/JPL/UNIVERSITY OF ARIZONA, NASA/JPL-CALTECH/SSI/HAMPTON UNIVERSITY, NASA



## SURFACE OF TITAN

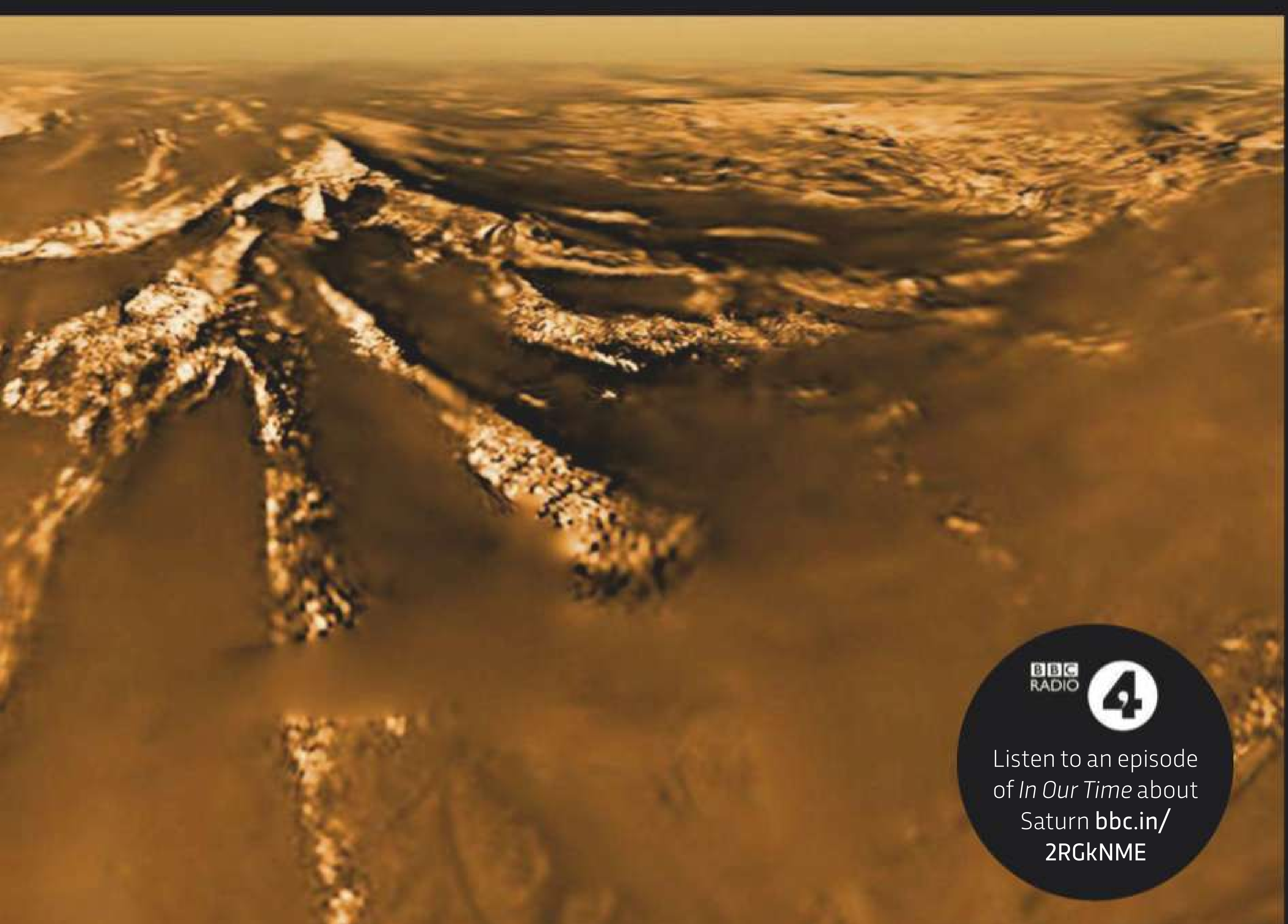
The Huygens probe captured the data used to create this Mercator projection of Titan's surface as it descended through the moon's nitrogen-rich atmosphere. These composite images depict a rugged landscape, eroded by rivers of methane and striated with regions of dark hydrocarbon dunes.

## THE ROSE: SATURN'S NORTH POLAR VORTEX

**In this false-colour image, in which red indicates lower clouds and green depicts high ones, the vast storm swirling above Saturn's north pole resembles a red rose – albeit one stretching 2,000km across and with winds blasting at over 500km/h. The image was captured by the narrow-angle camera on NASA's Cassini spacecraft – the first time this pole was photographed.**

## NORTHERN STORM

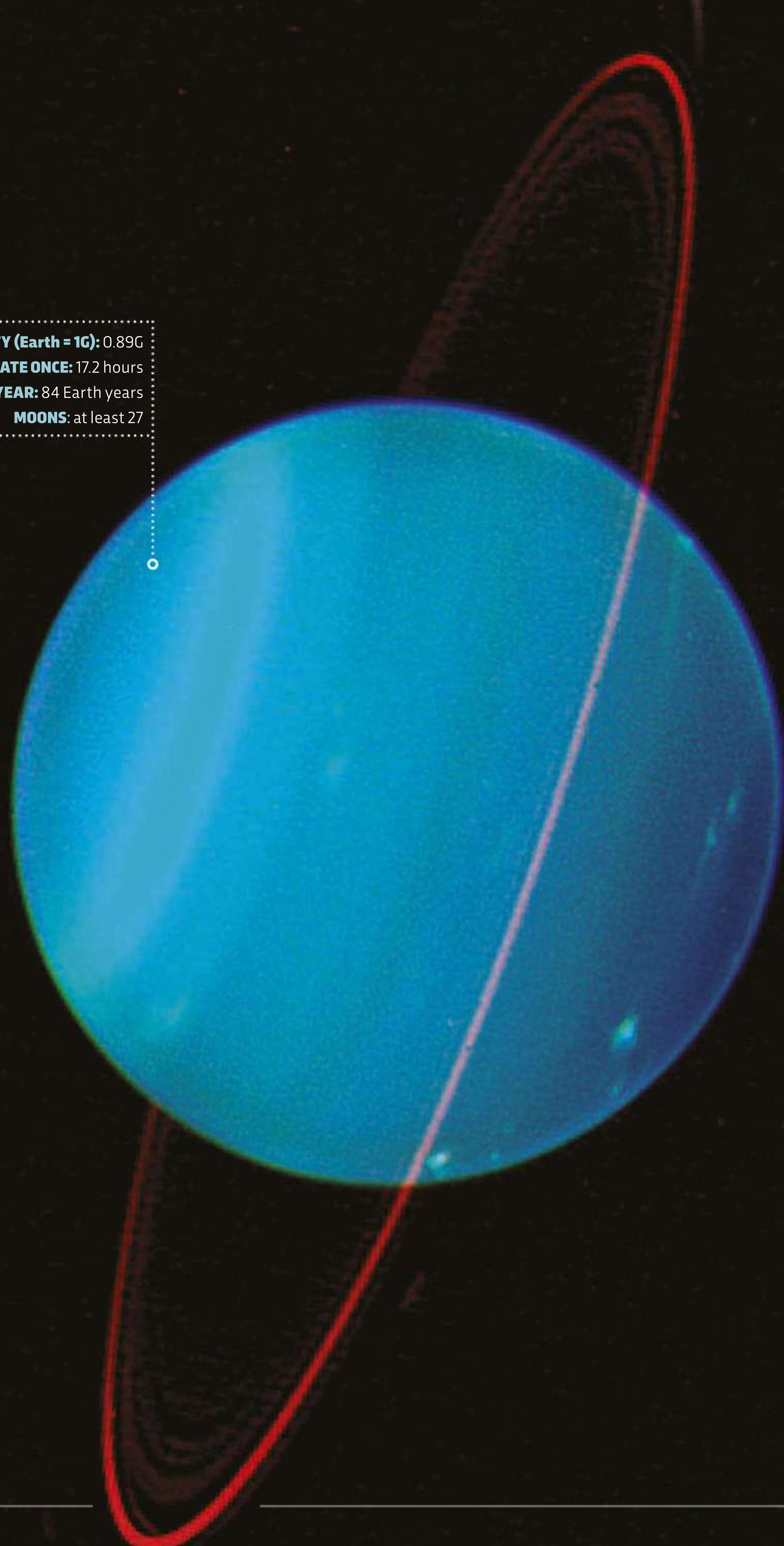
**The head of this vast convective thunder-and-lightning storm, first detected by Cassini in December 2010 and depicted in this false-colour image, moved west around the planet over a period of nearly nine months. It formed a vortex up to 12,000km across and eventually consumed itself when it made a full circuit of the planet – about 300,000km – and hit its own tail.**



BBC RADIO 4

Listen to an episode of *In Our Time* about Saturn **bbc.in/2RGkNME**

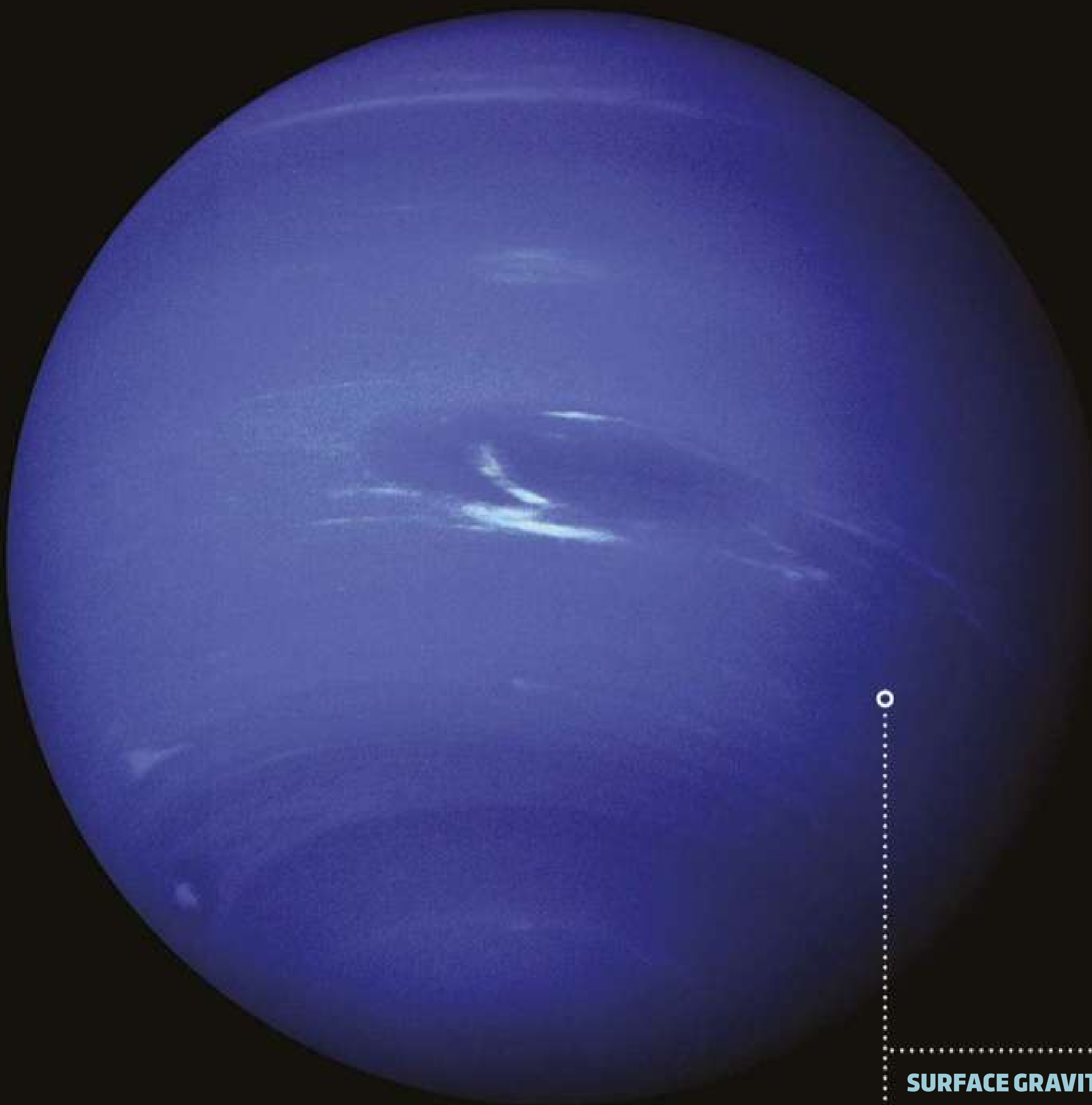
**Will Gater** is an astronomy journalist, author and astrophotographer.




BBC RADIO 4

Watch an episode of *The Sky at Night* with archive footage of Sir Patrick Moore talking about Voyager 2's flyby of Uranus **bbc.in/2Mvftpu**

CALIFORNIA ASSOCIATION FOR RESEARCH IN ASTRONOMY/SCIENCE PHOTO LIBRARY, NASA



**SURFACE GRAVITY (Earth = 1G):** 1.14G
**TIME TO ROTATE ONCE:** 16.1 hours
**YEAR:** 165 Earth years
**MOONS**: at least 14

# URANUS & NEPTUNE

At the edge of our Solar System lie these two ice giants, which we know very little about

The distant worlds are so cold that their rocky cores have become wrapped in a layer of water ice, hidden beneath a thick hydrogen atmosphere. The first, Uranus, is unlike the other giant planets due to its calm and featureless clouds, coloured blue by methane in the upper atmosphere. Uranus is tilted onto one side, meaning that it takes an entire 84-year orbit around the Sun for all of the planet to feel sunlight.

The second ice giant, Neptune, is the farthest planet from the Sun – 4.5 billion kilometres away, but its greater internal heating than Uranus drives the winds on Neptune to reach speeds of 2,400km/h, the fastest in the Solar System.

These two remote planets have only ever been visited once, when the Voyager 2 probe passed them in the late 1980s. But NASA plans to return and is discussing possible mission concepts, such as flybys, orbiters or even a craft that would dive into the atmosphere of Uranus. Another mission to Neptune would orbit the planet and analyse its largest moon, Triton.

# PLUTO

New Horizons' flyby of Pluto revealed a rusty red surface and a heart-shaped region relatively free of impact craters, suggesting it's a geologically complex dwarf planet.

**SURFACE GRAVITY (EARTH = 1G):** 0.06G
**TIME TO ROTATE ONCE:** 6.4 Earth days
**YEAR:** 248 Earth years
**MOONS**: 5

# THE DWARF PLANETS

The discovery of distant bodies in the outer Solar System has had a profound effect on planetary science and our definition of what a planet is

WORDS: **IAIN TODD**

Most of us will remember sitting in science class at school and learning about the nine planets that orbit the Sun. Since then a vast multitude of rocky, icy bodies has been found on the edge of the Solar System, causing Pluto to be reclassified as a dwarf planet and reducing the Solar System's planetary roster by one.

Discovered by American astronomer Clyde Tombaugh in 1930, for most of the 20th Century, Pluto was considered the most distant planet in our cosmic neighbourhood, but that all began to change in the early 1990s.

The year 1992 saw the first confirmed detection of exoplanets, but also marked a new era of discovery closer to home, on the edge of the Solar System. That year, the first of over 1,000 rocky bodies – now known as Trans-Neptunian Objects (TNOs) – was discovered orbiting beyond Neptune in a ring of 4.5-billion-year-old cosmic debris called the Kuiper Belt. As the number of known TNOs grew over subsequent years, their classification criteria grew cloudier. If Pluto belonged to this group, surely it would not be long before other objects were discovered that could rival it in size and mass? Should such objects also be considered planets?

**"The discovery of the Kuiper Belt in general is directly related to the demotion of Pluto"**

In 2003, astronomers Mike Brown, Chad Trujillo and David Rabinowitz discovered Eris, a large Kuiper Belt Object orbiting far beyond Pluto. Cue the International Astronomical Union (IAU), a 100-year-old organisation of over 10,000 astronomers and the authority on classifying celestial bodies. As a result of the discovery, the IAU asked its members at its 2006 General Assembly to debate the definition of the term planet and decided upon three key properties. The first is simple: a planet must orbit the Sun. Secondly, it must exist in a state of hydrostatic equilibrium; that is, with sufficient gravity that it takes on a spherical or nearly spherical shape. Thirdly, it must be able to clear its own orbital path. Pluto doesn't meet this final criterion and so the term dwarf planet was coined for it, Eris and other objects that don't quite fit the planetary prerequisites.

"The discovery of the Kuiper Belt in general is directly related to the demotion of Pluto," says Alessandro Morbidelli, an Italian astronomer at the Observatoire de la Côte d'Azure and a member of the IAU. Morbidelli

NASA/JHUAPL/SWRI

## THE FIVE DWARFS

*What we know so far about the Solar System's dwarf planets*

### PLUTO

The best-known dwarf planet has a thin blue atmosphere, five known moons and tall mountains topped with methane snow.

### ERIS

This dwarf planet is likely rocky, but -243°C temperatures could cause its atmosphere to freeze and fall as snow. It has one small moon named Dysnomia.

### CERES

Moonless and with no atmosphere but showing evidence of water ice, water vapour and geological activity. Ceres is the smallest known dwarf planet.

### HAUMEA

The first known ringed Kuiper Belt Object, this rugby ball-shaped dwarf planet is one of the fastest rotating large bodies in the Solar System.

### MAKEMAKE

Little is known about this bright Kuiper Belt Object, but it appears reddish brown, has one known moon, may have a thin atmosphere and frozen ethane and methane on its surface.

was present during the 2006 debate when Pluto's fate was sealed.

"Pluto doesn't destabilise the other bodies in the Kuiper Belt, so it doesn't really behave in the way that we'd expect a planet to behave. This prompted a big problem, because if Pluto is a planet, then Eris is a planet, and it was difficult to leave the population of planets in such an undefined state. What about something half the size of Pluto? Where do you put the boundary? We had to decide, otherwise you would have schoolchildren asking: 'How many planets are there?' And their teacher replying: 'Well, we don't really know.' So it was a bit of a mess."

The list of officially recognised dwarf planets currently numbers five: Pluto, Eris, Ceres, Haumea and Makemake. Pluto is the largest, yet is still only about two-thirds the width of Earth's Moon.

**EXPLORING PLUTO**

The two Voyager spacecrafts' journeys through the Solar System in the 1970s and '80s did not include Pluto, so it was left to NASA's New Horizons probe to give us our first close-up view of the dwarf planet. The probe's flyby on 14 July 2015 revealed a heart-shaped nitrogen ice glacier on the surface of Pluto. Now known as the Tombaugh Regio, it's the largest known glacier in the Solar System. This region is relatively crater-free, while others are covered in impacts, suggesting a complex geological past. New Horizons also revealed Pluto to be a rusty reddish colour, which may indicate a surface layer of dark tholins – complex molecules created by sunlight hitting methane in its thin atmosphere. This methane may also be responsible for bright features seen on Pluto's 3,000km-long Cthulhu Macula mountain range, the gas freezing as ice on top of its rocky peaks.

The only other dwarf planet visited by human spacecraft is Ceres, in the asteroid belt between Mars and Jupiter. In 2015, NASA's Dawn mission found that Ceres has a varying internal density, which scientists attribute to dense rock having settled below a water-rich crust early in the dwarf planet's history. Ceres may be about 25 per cent water ice by mass, making it the most water-rich body in the Solar System after Earth. And yet, it's incredibly salty. One of the most

NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/SOUTHWEST RESEARCH INSTITUTE, NASA, ESA, AND A. SCHALLER, NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA, A. FEILD (SPACE TELESCOPE SCIENCE INSTITUTE), IAU, M. KORNMESSER (ESA/HUBBLE)

# THE HUNT FOR PLANET X

*The discovery of distant dwarf planets is helping to solve one of the Solar System's greatest mysteries*

**Astronomers continue to search the region beyond Neptune for a hypothetical ninth planet known as 'Planet X'. The most recent detection is 'Farout' – a dwarf planet, which has yet to be officially recognised as such. This body is 3.5 times farther from the Sun than Pluto, and observations suggest it and other distant objects are clustered together, their orbits apparently being shepherded by an unseen large super-Earth planet. Astronomer Scott Sheppard, one of Farout's discoverers, said: "These distant objects are like breadcrumbs leading us to Planet X. The more of them we can find, the better we can understand the outer Solar System and the possible planet that we think is shaping their orbits: a discovery that would redefine our knowledge of the Solar System's evolution."**

An artist's impression of 'The Goblin' – another dwarf planet yet to be officially recognised as such. It's so far from Earth it's too faint to detect for 99 per cent of its orbit

ROBERT MOLAR CANDANOSA/SCOTT SHEPPARD/CARNEGIE INSTITUTE FOR SCIENCE

prominent features discovered by Dawn was bright spots in Ceres' Occator crater. These are thought to be deposits of sodium carbonate and the saltiness of Ceres could explain why it appears to be geologically active despite being so small and cold, as the presence of salt would lower the freezing point of its water.

Little is known about the remaining three dwarf planets, having so far not been explored by human spacecraft, yet perhaps most intriguing is Haumea. It rotates about once every four hours, and the force of this rapid spin has squished Haumea into a rugby ball shape. The reason for its ferocious rotation may be the result of a collision with another object billions of years ago and the same impact may have created the debris that formed its two known moons, Namaka and Hi'iaka. Rings were also discovered around Haumea in 2017 by astronomers who observed it passing in front of a distant star.

The case is growing for a mission to explore dwarf planets. "Every time we visit something new, we find something new," says Morbidelli. "There's a diversity among these bodies and we are far from understanding it. Ceres and Pluto are clearly different: Ceres is smaller, it's in a different part of the Solar System, it has a different origin, formation and dynamic evolution. Visiting even just one more dwarf planet in the Kuiper Belt and comparing it with Pluto would be extremely insightful."

We once thought the region beyond Neptune was empty, yet the more we discover, the more it appears to be anything but. Who knows? Further encounters may reveal more dwarf planets and other bodies ripe for close inspection.

Listen to a programme about how Pluto was stripped of its status as a planet **bbc.in/2FVFHR9**

**Iain Todd** is a science journalist and staff writer at *BBC Sky at Night* magazine.

BBC RADIO 4

Listen to an episode of *In Our Time* about asteroids bbc.in/2FWBA7I

ILLUSTRATION: MAGIC TORCH

THE CHALLENGING MISSIONS TO HARVEST

# SPACE ROCKS

The pioneering crafts that will return the largest haul of space dirt to Earth since NASA's final Apollo mission in the 1970s

WORDS: **LEWIS DARTNELL**

OSIRIS-REx. Hayabusa2. Make a note of these two names: you're going to be hearing a lot about them over the coming months. These spacecraft – one operated by NASA and the other by the Japan Aerospace Exploration Agency, JAXA – are both now orbiting around a target asteroid. They promise to teach us a great deal about the origins of the Solar System, how we might deflect an asteroid on a collision course with the Earth, and even the molecular origins of earthly life.

Both NASA's OSIRIS-REx and JAXA's Hayabusa2 are sample-return missions, which means that not only will they touch gently onto their asteroid's surface to collect a scoop of its ancient material, but they will then return it safely back to eagerly waiting scientists on Earth. This sort of return trip mission within deep space is fabulously complex, and both probes are marvels of engineering. The Japanese probe is a follow-up to their earlier asteroid mission, Hayabusa, which returned a small sample from the asteroid Itokawa in 2010. Despite suffering numerous glitches, Hayabusa racked up a string of accomplishments, including being the first spacecraft designed to land and take off from an asteroid and the first to return an asteroid sample to Earth. Hayabusa2 uses the same basic spacecraft structure as its predecessor, but incorporates more backup systems to improve reliability, along with some technological advances. As well as upgrades to the communication antenna and guidance systems, Hayabusa2's ion engines are 25 per cent more powerful than its predecessor's, and the probe will be able to autonomously control its own final descent to the remote asteroid's surface. Hayabusa2 is also like a mothership in its own right – it will deploy a small lander and three rovers onto the asteroid's surface

for a closer look, which can hop around the landscape to different locations.

Meanwhile, NASA's OSIRIS-REx is the first ever US asteroid sample-return mission. This spacecraft is about twice the size of Hayabusa2 and, rather than using ion engines, it will fire standard rocket thrusters to accelerate on its trajectory to its target asteroid. Both missions are surveying their target asteroids for about a year and a half, mapping the surfaces and remotely detecting minerals using spectroscopy. Scientists will then use these results to help them decide the best spot on their asteroids for Hayabusa2 and OSIRIS-REx to descend to collect their samples.

**These kind of space rocks are thought to have delivered a lot of water to primordial Earth**

#### TIME CAPSULES

Asteroids are important because they represent primordial material left over from the formation of the planets. They are like time capsules from before the creation of the Earth, preserving matter since the beginning of the Solar System. By studying them up-close, scientists hope to be able to answer some pretty fundamental questions about the formation and development of the Solar System. Specifically, it will help us to understand how planets like the Earth were born, by allowing us to observe the material from which rocky planets form.

Even more excitingly, both OSIRIS-REx and Hayabusa2 are orbiting carbonaceous asteroids. These kind of space rocks have a high percentage of carbon compounds as well as water-containing minerals, and are thought to have delivered a lot of water to the primordial Earth to fill our oceans, along with organic chemicals like amino acids. As Dr Yuichi Tsuda, project manager for Hayabusa2, puts it, "The primary reason we chose our target asteroid is that it is a C-type [carbon-rich]. Telescope observations suggest that it should contain lots of carbon as well as water-related minerals, and so give us important clues as to how life on Earth became possible. We've never explored or sampled this type of asteroid before, so these missions are really exciting".

Organic chemistry forms the building blocks of all life on Earth. Cells of organisms are made up of certain molecules joined together into long chains: amino acids that build our proteins; nucleotide bases that make DNA and RNA; and the long, oily chains that make up the outer membranes of cells. We know that many of these chemical building blocks are formed in the cosmos – through what is known as 'astrochemistry'– in the cold gas clouds floating through space, as well as the warmer regions around old, dying stars. When this material pulls together under gravity as a new solar system forms, the organic molecules become incorporated into asteroids and comets. So while asteroids don't deliver fully-formed

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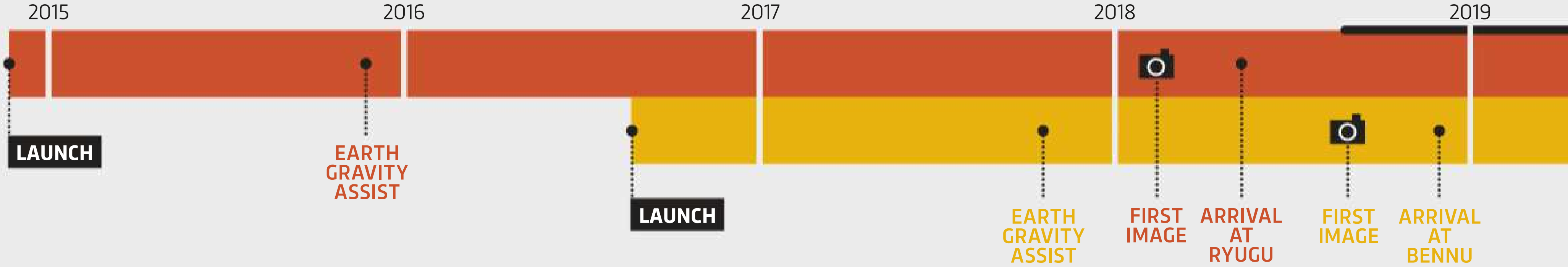
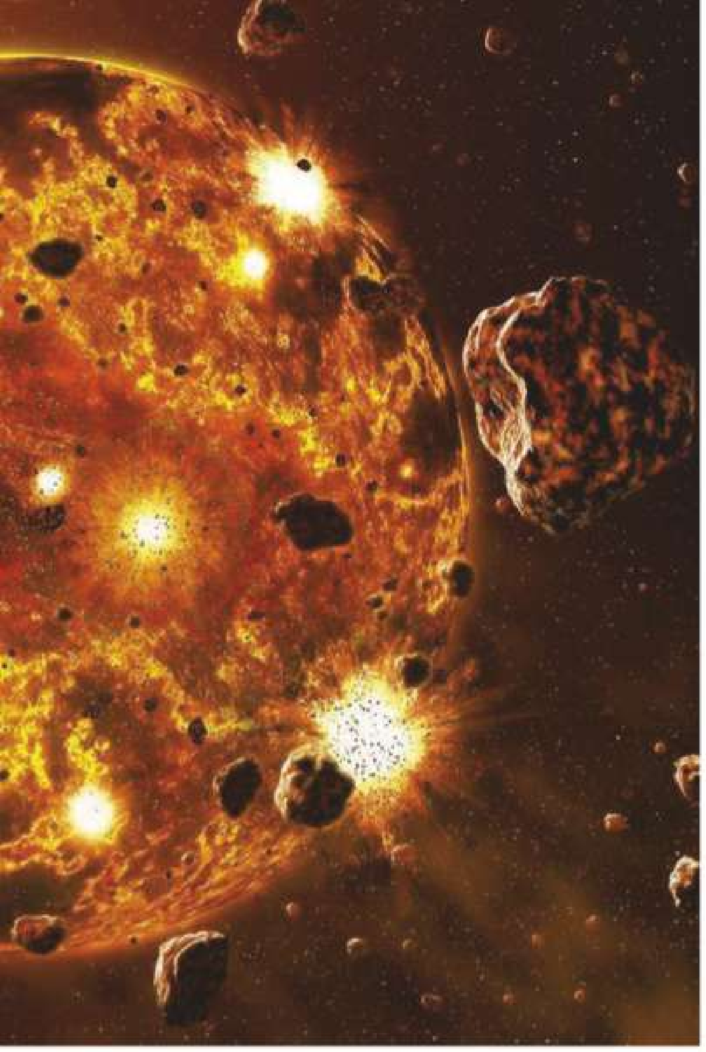
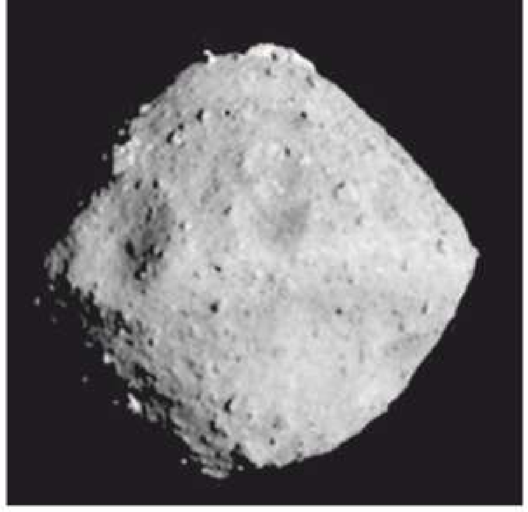
## Hayabusa2 & OSIRIS-REx OPERATIONS TIMELINE







ABOVE: Asteroids are time capsules from the Solar System's formation

CENTRE TOP: A recent image of asteroid Ryugu from Hayabusa2

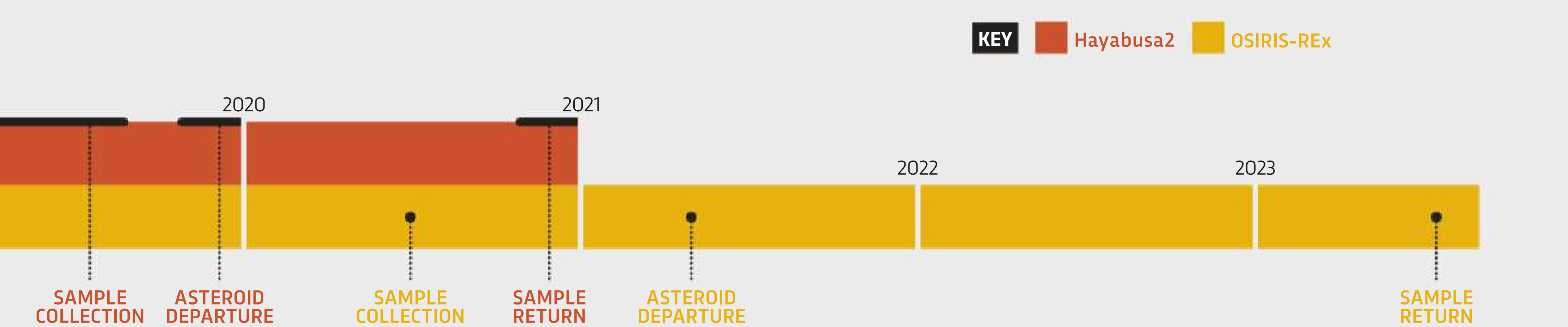
CENTRE BOTTOM: Extracting samples from the first Hayabusa mission upon its return to Earth

RIGHT: OSIRIS-REx being assembled prior to its launch back in 2016

cells to young planets, they may have provided many building blocks for the origin of life – and finding organic molecules on these asteroids would offer support for this idea.

Organic molecules like amino acids have previously been found in meteorites that have landed on the Earth, but these missions will be the first time that scientists will be able to get their hands on carbonaceous material directly from an asteroid. Although meteorites naturally deliver us lumps of primordial space rock, as soon as they land they're susceptible to contamination from Earth's environment. Hence, sample-return missions are important to researchers – material is collected from the source and hurried back via a robotic courier. Prof Sara Russell is a planetary scientist at London's Natural History Museum, and will run some of the preliminary studies on the material returned by OSIRIS-REx. "I've worked on meteorites my whole career, but we're never really sure what sort of asteroid, or where in the Solar System, they've come from," she explains. "OSIRIS-REx is like going on a grand field trip to pick our own sample, and when it comes back to Earth in 2023 it will be a meteoriticist's dream come true!"

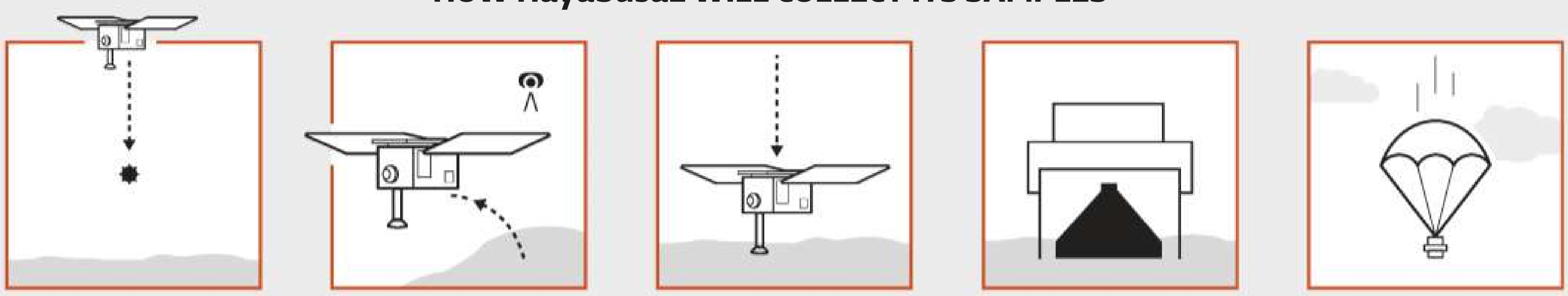
Both NASA and JAXA chose their target asteroids because they offer pristine carbonaceous material for researchers to study. But they also needed asteroids that are roughly the right size (with enough gravity for their probes to orbit), that aren't spinning too quickly (so that the probes can 'touch down' safely), and that are in a near-Earth orbit that the probes can actually reach. "Asteroids that fit all



# Hayabusa2

**Launch mass:** 600kg
**Size:** 1 x 1.6 x 1.3m
**Target asteroid:** 162173 Ryugu
**Launch:** 3 December 2014, Tanegashima Space Centre, Japan
**Sample size to be collected:** Up to 300mg
**Sample return:** December 2020
**Power:** Two solar arrays, generating between 1.4kW and 2.6kW
**Propulsion:** Four ion engines and 12 rocket engines
**Fuel:** Xenon and hydrazine
**Estimated cost:** ¥16.4bn ($150m)

## HOW Hayabusa2 WILL COLLECT ITS SAMPLES



1 The probe approaches asteroid Ryugu, deploying its impactor at an altitude of 500m. When detonated, this fires a 2.5kg copper projectile into the asteroid's surface, blasting out a 2m-wide crater.

2 Before detonation, the probe deploys a camera into space to watch the explosion, and escapes to the far side of the asteroid in order to protect itself.

3 When safe to do so, Hayabusa2 returns to the crater site and uses its rocket thrusters to descend, until its extendable 'sampler horn' touches the surface.

4 The sampler horn fires out a metal projectile, collecting the resulting debris in the re-entry capsule.

5 The capsule parts from its mothership on return to Earth, parachuting into the RAAF Woomera Range Complex in South Australia. Hayabusa2 moves into an orbit around the Sun.

these criteria are actually quite rare," says Prof Hitoshi Kuninaka, who has been leading the development of Hayabusa2's ion engines. The NASA scientists picked asteroid 101955 Bennu for their mission, whereas JAXA's Hayabusa2 is orbiting 162173 Ryugu. And they will collect their samples in a spectacularly audacious way.

OSIRIS-REx will slowly lower itself towards the asteroid's surface, without actually landing, and fold its solar panels upwards to protect them. Here, it will extend a robotic arm and puff a sharp burst of nitrogen gas to blow up particles into its collection head. After just five seconds, the sample collector will close and OSIRIS-REx will automatically begin to back away from the surface. With anything between 60g and 2kg gathered, this precious cargo will be sealed into a re-entry capsule and fired back towards the Earth, where it'll parachute safely to the ground in Utah to be picked up.

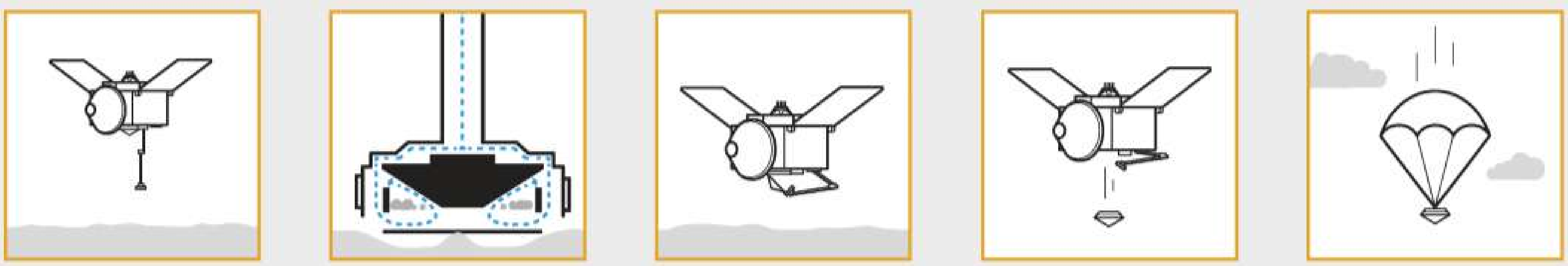
Hayabusa2 is even more innovative. It carries a device called the Small Carry-on Impactor (SCI), consisting of a 2.5kg copper projectile and a shaped charge of plastic explosive. This explosive will fire the copper impactor into Ryugu's surface at over 7,000km/h, blasting out a crater while Hayabusa2 flies around the far side of the asteroid to protect itself from the flying shrapnel. A camera released by the probe will watch the impact, transmitting the images to Hayabusa2 before the probe returns to the crater to collect its sample. This will enable Hayabusa2 to analyse the interior structure of the asteroid, and to gather material that has

ILLUSTRATION: PHIL ELLIS

# OSIRIS-REx

**Launch mass:** 2,110kg
**Size:** 2.43 x 2.43 x 3.15m
**Target asteroid:** 101955 Bennu
**Launch:** 8 September 2016,
Cape Canaveral Air Force Station, Florida, USA
**Sample size to be collected:** Between 60g and 2kg
**Sample return:** September 2023
**Power:** Two solar arrays,
generating between 1.2kW and 3kW
**Propulsion:** 28 rocket engines
**Fuel:** Hydrazine
**Estimated cost:** $800m

## HOW OSIRIS-REx WILL COLLECT ITS SAMPLES



1. The probe approaches the surface of asteroid Bennu, delicately positioning itself above the asteroid (without landing) using a pair of specialised low-thrust rocket engines.
2. OSIRIS-REx briefly touches the asteroid with its 3m-long robotic arm, using a puff of nitrogen to blow loose rock and dust into the collection head at the end of the arm.
3. The collection head is then stowed inside the Sample Return Capsule (SRC), ready for the journey home.
4. As OSIRIS-REx nears Earth, it releases the SRC, manoeuvres away and enters an orbit around the Sun.
5. The SRC parachutes into the Utah desert, complete with sample.

not been exposed to ultraviolet radiation and the solar wind.

Beyond teaching us about the origins of the Earth and the conditions for life, the probes have another critical aim: to help prevent a cataclysmic cosmic collision. As Bennu and Ryugu orbit the Sun close to the Earth, they are also exactly the sort of asteroids that present a potential hazard to our planet. The orbit of Bennu, for example, brings it close to the Earth every six years, and it's been calculated that there's a 1 in 1,410 chance that it might hit us between the years 2169 and 2199.

OSIRIS-REx will help us understand how the orbit of asteroids like Bennu might change over time through a process known as the Yarkovsky effect. This is a tiny force caused by the emission of infrared radiation from the Sun-warmed surface of an asteroid, but over long periods it can significantly nudge an object's orbit. OSIRIS-REx is studying this effect and what it means for the probability of Bennu impacting the Earth in the future. The probe is also measuring the asteroid's physical properties. Is it a single body, or perhaps composed of multiple large boulders held together only loosely? We'd need to know this before deciding the best deflection technique.

These missions are spectacular not just for their audacity, but also for the sheer breadth of their vision. From the origins of life on our planet to protecting the life that now clings to survival here, the probes promise to offer new insights into our place in the cosmos.

**Prof Lewis Dartnell** is an astrobiology researcher at the University of Westminster. His latest book is *Origins: How The Earth Made Us*.

# WARNING ASTEROID IMPACT ALERT!

Practising smashing a satellite into a large space rock could one day save Planet Earth

WORDS: **ELIZABETH PEARSON**

News flash: we've found an asteroid bigger than the one that killed the dinosaurs and it's heading straight for us! Thankfully, this scenario is yet to play out beyond films and TV. But the threat of an asteroid impacting Earth is very real.

Around 66 million years ago, an asteroid impact blasted enough soot into the atmosphere to cause extreme global cooling,

NASA's DART probe will launch a cubesat to record it crashing into Didymoon

ESA/SCIENCEOFFICE.ORG

wiping out 75 per cent of all life on Earth, including the dinosaurs. It's only a matter of time before another huge space rock is destined for a high-speed date with our planet.

But a giant meteor flying straight towards Earth might not be as fatal as it was 66 million years ago. As science fiction author Larry Niven once said, "The dinosaurs are extinct because they didn't have a space programme." We do.

The world's space agencies are finally rising to the challenge to protect humanity from the fate of our Cretaceous ancestors by mounting a mission that could give us the skills we need to change the course of a killer space rock – the Asteroid Intercept and Deflection Assessment (AIDA), the first ever attempt to change the course of an asteroid.

The mission starts in 2021, when NASA

launches the Double Asteroid Redirection Test (DART), a spacecraft with a seemingly simple task in mind.

"We're going to take a spacecraft which is around 100kg in mass and ram it into the moon of an asteroid," says Andy Rivkin of the Johns Hopkins University. "Then we're going to see what the effect of our ramming it is."

The orbit of asteroid Didymos brings it within a mere 10 million km of Earth. In space terms, that's right next door. DART's actual target is the 170km space rock in orbit around it, nicknamed 'Didymoon'. And by target, NASA means just that. DART will take aim, and smash directly into the moon.

"We're going straight in," says Rivkin. "There's no orbit. We get one shot."

This high-speed crash should speed up Didymoon's velocity by a few millimetres per second. It's a tiny amount, but it is enough to change the moon's orbit. With enough time, a similar technique – known as 'kinetic impactor' – could one day be used to change the path of an Earth-threatening asteroid so that it dodges past our planet.

After DART's crash, NASA will watch Didymoon to see if the time it takes to orbit (currently 11.9 hours) gets any shorter. Seeing this change will not only tell the researchers that the mission was successful, but how successful it was. It is one thing to be able to change an asteroid's orbit, it's another to be able to predict how much it will change by.

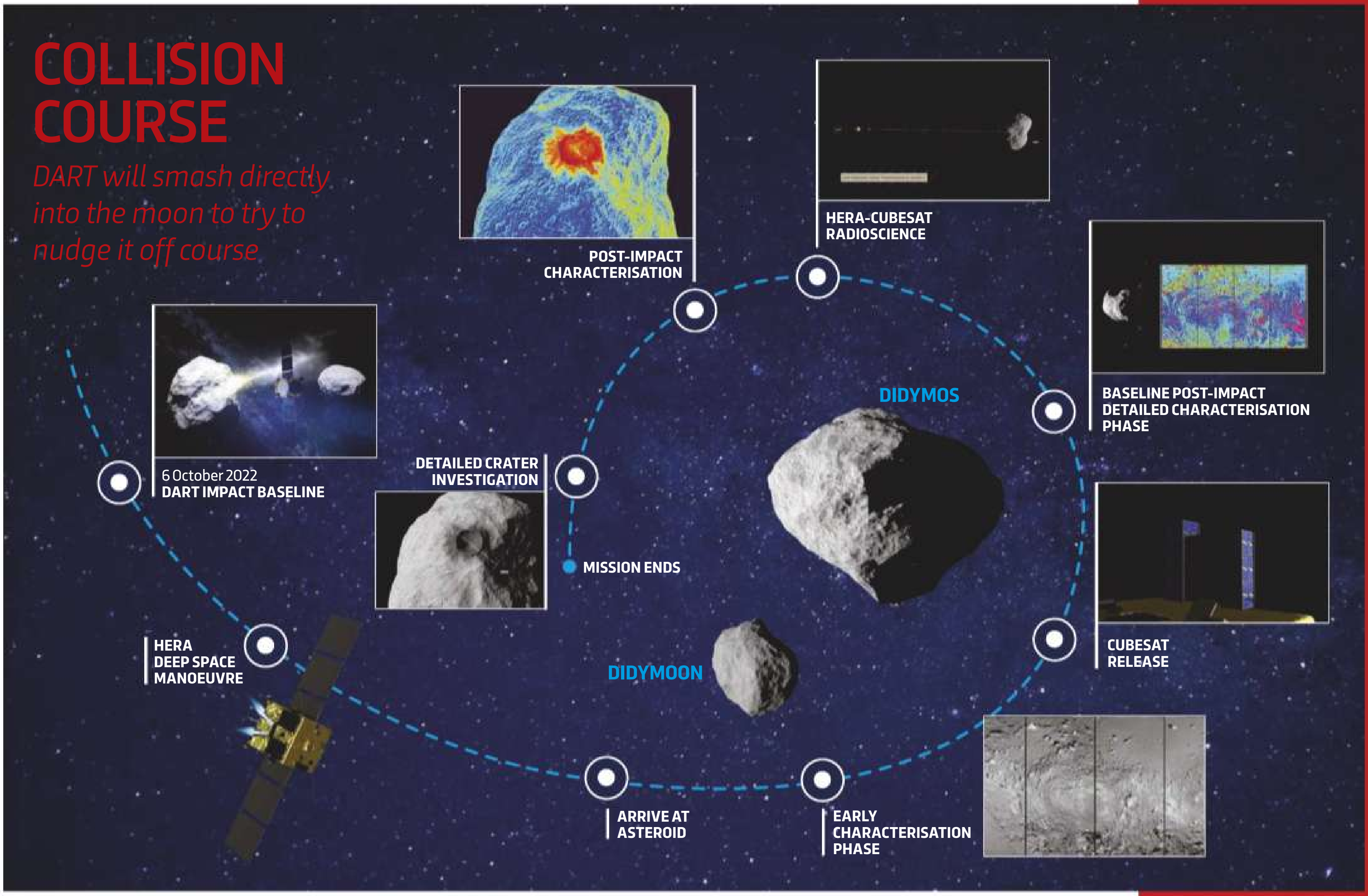
It is this predictive ability that the second stage of the mission will look into. Just before impact, DART will launch a cubesat made by the Italian Space Agency. The cereal box-sized spacecraft, nicknamed 'SelfiSat', will watch the impact, taking pictures of the crash site to help geologists understand exactly what effect

BBC RADIO 4

Listen to a programme about enthusiasts who scan the skies for asteroids in a bid to protect life on Earth **bbc.in/2CBwU3a**

## COLLISION COURSE

*DART will smash directly into the moon to try to nudge it off course*




ESA, NASA/JHUAPL

**Asteroids are the only natural threat that we can predict, but also prevent**

DART has had on the moon.

We won't get a detailed view of what happened, though, until 2026 when the European Space Agency's Hera spacecraft enters into orbit around Didymos and gets to know both main asteroid and moon in incredible detail.

"We need to get a precise measurement of the mass of this little moon," says Ian Carnelli, the manager of the Hera mission.

Knowing the mass is vital as it tells us exactly how big of a speed change we would expect to see from DART's crash landing. But it will take more than that to fully understand the DART impact.

"We'll get a measure of the surface roughness, whether there are boulders on the surface, whether the interior structure has some voids. Because all of these affect the deflection," says Carnelli.

This is vital to fine-tune the forecasting software researchers would use should we ever need to mount a real mission against an extinction level impact. By the end of AIDA we should not only know whether it is possible for us to deflect an asteroid, but be able to predict where we would be sending it.

"Asteroids are the only natural threat that we can predict, but also prevent," says Carnelli. "When kinetic impactor is validated, then we really retire the risk of an asteroid impacting the Earth."

It has taken 66 million years, but planet Earth is finally ready to take out an insurance policy against the threat of killer asteroids.

**Elizabeth Pearson** is a space journalist and news editor at BBC *Sky at Night* magazine.

## HOW TO SAVE EARTH

*To dodge an asteroid follow these three easy steps...*

### 1 Search

We can't deflect an asteroid unless we know it's coming. Telescope surveys already scan the sky searching for potentially hazardous space rocks, and we think we know the location of over 90 per cent of extinction level asteroids, but one even a few dozen metres across could cause serious damage.

### 2 Characterisation

Once we know an asteroid is coming, we need to know what it's like. Size, shape, composition and density all have an effect on how dangerous an asteroid is, but also how we can deal with it. A heavy asteroid would take more mass to stop, while a low density one might break apart.

### 3 Mitigation

If we know about an asteroid a decade in advance, we can give it a gentle nudge using a similar technique to the DART mission. Over several years, a small change in course would be enough to avoid the Earth. However, if we don't get enough warning, more drastic measures may have to be taken, such as using a nuclear bomb's shockwave.

# THE KUIPER BELT

Starting at Neptune and stretching out to 7.5 billion kilometres from the Sun, this ring of small, icy bodies represents the remnants of the Solar System's formation

MARK GARLICK / SCIENCE PHOTO LIBRARY

In the last few years, the Kuiper belt has finally been giving up its secrets, thanks to the New Horizons spacecraft. In July 2015, the craft flew past Pluto, transforming the dwarf planet from an astronomical object to a geological one, rich with surface detail undetectable from Earth. Then, earlier this year on the 1st January it flew within 3,500 kilometres of one of the fossil building blocks of the planets and one of the most primitive bodies in the Solar System – 2014 MU69, now renamed Ultima Thule from a medieval term meaning 'beyond the known world'.

Whereas Pluto has an active surface, what excites planetary scientists about Ultima Thule is that it is pristine. It's thought to have remained unchanged since the birth of the Solar System 4.55 billion years ago and, therefore, promises to reveal clues about how the planets formed and evolved around the Sun.

Orbiting 1.6 billion kilometres beyond Pluto, or 43 times further from the Sun than the Earth, Ultima Thule is the most distant object that a spacecraft has ever flown by.

New Horizons' journey continues. By 2025, it will be almost 4 billion kilometres further away, and heading out into the wastes of interstellar space.



An artist's impression of Ultima Thule, which New Horizons flew past on New Year's Day

# THE MOST MYSTERIOUS OBJECTS IN THE SOLAR SY

COSMIC ENIGMAS THAT HAVE ASTRONOMERS SCRATCHING THEIR HEADS...

**WORDS**: COLIN STUART

## 'OUMUAMUA

*Could this cucumber-shaped object be a lone ranger from another galaxy?*

On 19 October 2017, the astronomer Dr Robert Weryk spotted an object whizzing through the Solar System while using the Pan-STARRS telescope at Haleakalā Observatory, Hawaii.

Dubbed 'Oumuamua (after the Hawaiian for 'scout'), this object is extremely elongated, possibly up to a kilometre in length but not more than 167 metres wide. It's travelling so fast that there's no way it can be gravitationally bound by the Sun. The only conclusion is it's an interloper that formed outside our Solar System and subsequently trekked all the way here. Estimates suggest it entered the Solar System in the Victorian era, but astronomers don't know exactly how long it wandered space alone before it got here. In August 2018, a study using data from the European Space Agency's Gaia telescope identified four stars that it would have passed close to in the last one to seven million years. Perhaps one of these was its home star.

So what is 'Oumuamua? At first, astronomers reckoned it was an asteroid, but a closer look at its motion threw up something strange: the Sun's gravity was not the only thing affecting its trajectory. "Most of the evidence points towards a comet," says Dr Colin Snodgrass, an astronomer at the Open University. Little jets of gas, caused when the comet's ice is warmed by the Sun, could be nudging it off its natural gravitational course. "It has some unusual properties compared with comets from our Solar System, though. We are still trying to figure out what causes these." Typically, comets reflect about 4 per cent of the light that falls on them. 'Oumuamua is more than twice as reflective.

Unfortunately, our chance for more observations is now over, as it has fled into the outer Solar System, journeying past Jupiter on a trajectory that will eventually see it leave our neighbourhood. It's already too faint to see.

ABOVE: Artist's impression of 'Oumuamua

ABOVE RIGHT: Elst-Pizarro can be seen zooming across the middle of this image, taken by the Schmidt telescope at La Silla Observatory

GETTY IMAGES, ESO

STEM

> **Astronomers reckoned it was an asteroid, but a closer look at its motion threw up something strange**

# ELST-PIZARRO

*Is it an asteroid? Is it a comet? This object seems to have properties of both*

Normally it's easy to tell asteroids and comets apart. Asteroids are solid lumps of rock and metal, capable of careering into planets and killing dinosaurs. You typically find them in the inner Solar System, particularly in the asteroid belt between Mars and Jupiter. Comets, on the other hand, are icy bodies that form on the outskirts of the Solar System. On their rare forays towards the Sun, their frozen bodies react with solar radiation to create spectacular tails.

An object known as Elst-Pizarro, however, refuses to be so neatly pigeon-holed. When it was first discovered in 1979, its orbit in the asteroid belt led to it being classified as an asteroid. Yet when it was examined more closely in 1996, it showed itself to have a tail – like a comet.

Astronomers first thought that the tail was debris from a collision, rather than something bestowed by the Sun's heat. But the tail's brightness and structure changed over time – pointing to an ongoing process, rather than a one-off event. The object's rapid rotation – a full spin in just 3.5 hours – also said comet. One possibility is that a collision exposed some subsurface ice on the body which is slowly being lost to space. If so, Elst-Pizarro would be an asteroid masquerading as a comet – until it has shed all of its exposed ice.

To settle the matter, space scientists had hoped to launch the Castalia spacecraft for a closer look in 2028. However, the mission failed to get the green light in the European Space Agency's 2016 round of funding.

# PLANET X

*Could our Solar System be hiding an enormous ninth planet, out beyond the orbit of Neptune?*

Astronomers are increasingly convinced there is a giant ninth planet lurking out beyond Neptune. The first clues came in 2014 when American astronomer Dr Scott Sheppard found a small dwarf planet candidate called 2012 VP113, orbiting an average of 250 times further from the Sun than the Earth. Its elongated orbit, which is significantly tilted relative to that of the planets, immediately stood out. "Nothing is currently known in the Solar System that could create 2012 VP113's orbit," says Sheppard.

While a few unusually aligned objects could be dismissed as an unlikely coincidence, now a total of 10 have been discovered, largely thanks to work by astronomers Dr Mike Brown and Dr Konstantin Batygin at the California Institute of Technology. With all of these objects sharing similar orbital properties, the chances of their alignment being a fluke drops to just 0.0001 per cent. The leading explanation is that there is an otherwise unseen planet herding these objects with its gravity.

For the planet to be acting in this way, it would have to be 10 times more massive than the Earth, take at least 10,000 years to orbit the Sun, and sit over 200 times further out than our planet. This enormous distance makes hunting it down and photographing it tricky. But the hunt continues. So far astronomers have covered about 30 per cent of the prime area the planet could be in. It'll take about another four years to cover the rest. In the meantime, the search for Planet X has heralded the discovery of more dwarf planets (see page 79).

**It would have to be 10 times more massive than the Earth**

ABOVE: Artist's impression of Planet X, which could be shaping the orbits of dwarf planets beyond Neptune

RIGHT: Astronauts aboard the International Space Station have reported some strange effects when passing over a certain region of the South Atlantic Ocean

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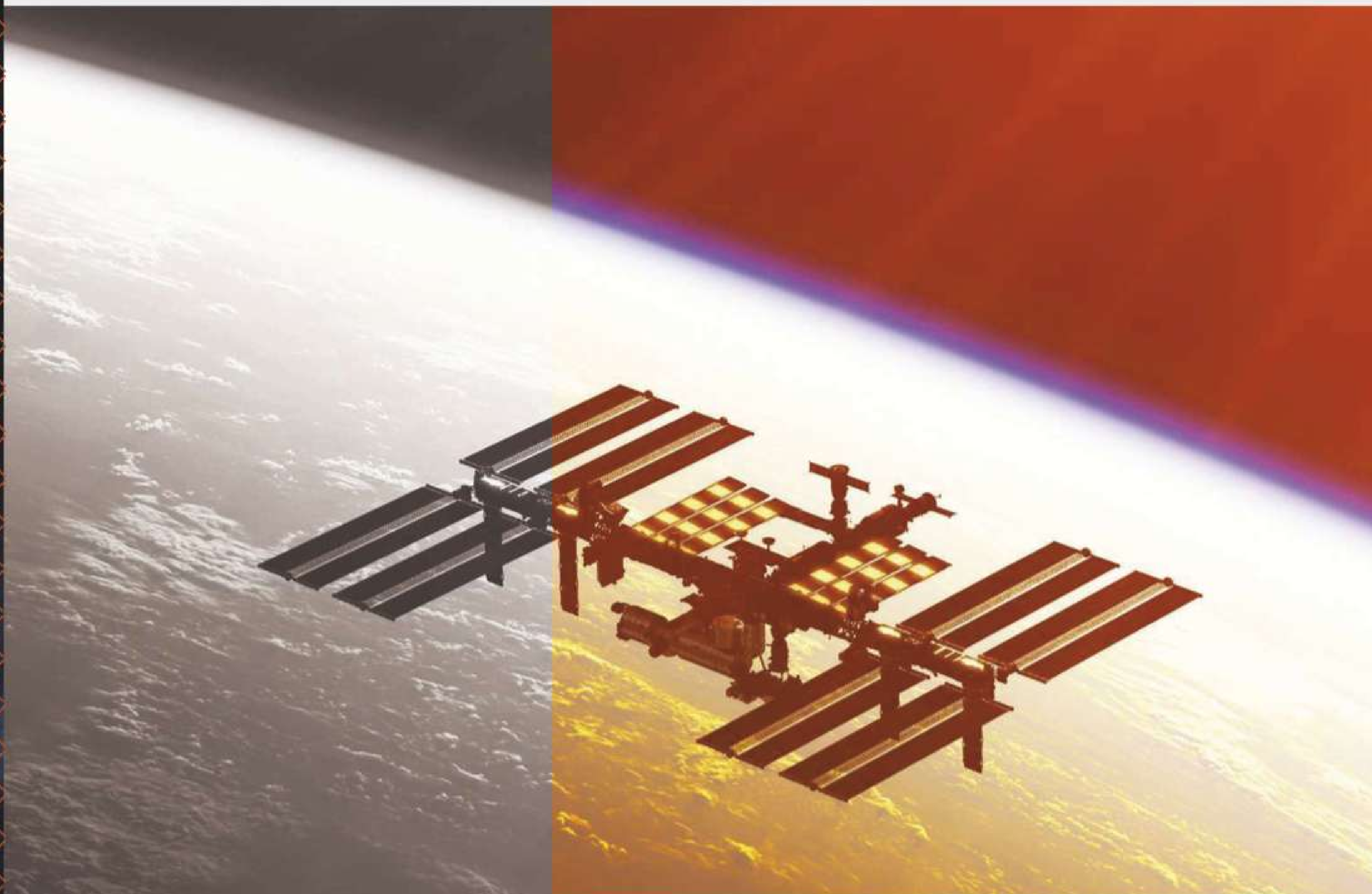


# THE BERMUDA TRIANGLE OF SPACE

*Strange things happen when astronauts on the International Space Station pass through a certain region of space…*

Imagine drifting off to sleep when, still with your eyes closed, you're suddenly startled by an intense flash of light. This is what some astronauts have reported when passing through the South Atlantic Anomaly (SAA) – a region of the Earth's magnetic field also known as space's Bermuda Triangle. Scientists believe it is linked to the Van Allen radiation belts – two rings of charged particles trapped in our planet's magnetic grasp. Our magnetic field is not perfectly aligned to the rotation axis of the Earth, which means these Van Allen belts are tilted. This leads to an area 200km above the South Atlantic where these radiation belts come closest to the Earth's surface. When the International Space Station passes through this area, computers can stop working, and astronauts experience cosmic flashes. Further study of the SAA will be crucial for the future of commercial space travel.

**Colin Stuart** is an astronomy speaker and author. His latest book is *How To Live In Space*.

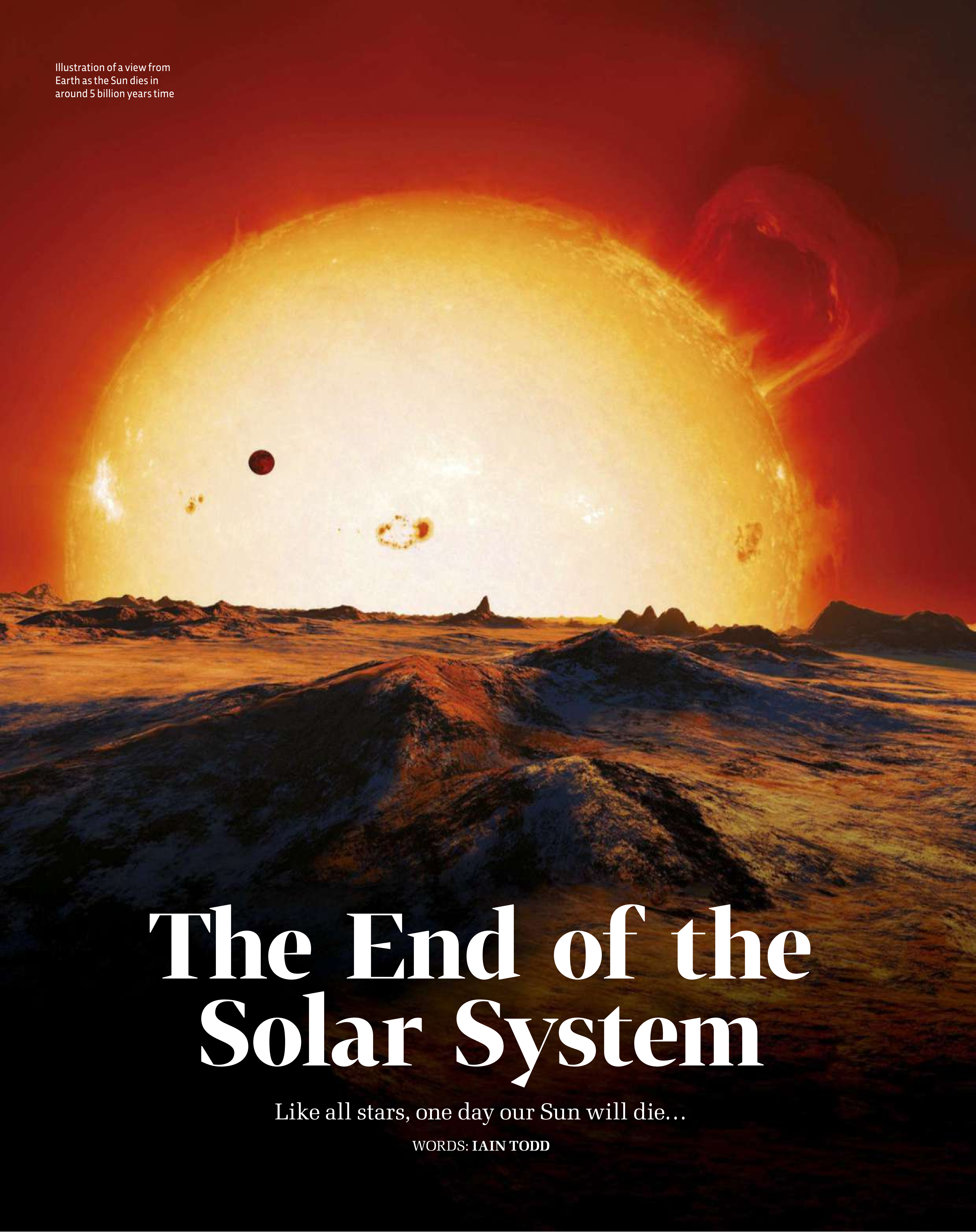
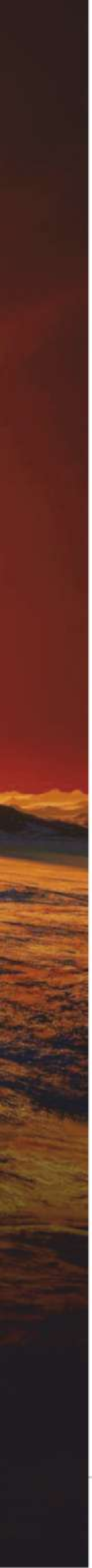


Illustration of a view from Earth as the Sun dies in around 5 billion years time

# The End of the Solar System

Like all stars, one day our Sun will die…

WORDS: **IAIN TODD**



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The Sun formed about 4.6 billion years ago and is set to survive in its current state, roughly speaking, for another 4.5 – 5.5 billion years. And while we can't predict what will happen in billions of years to come, knowledge of how stars evolve has enabled astronomers to broadly infer how the Sun's life is likely to play out. More massive stars may end their lives in an explosion known as a supernova, but that is not the likely scenario that awaits our own.

### 1. HYDROGEN-BURNING PHASE

Every second the Sun converts 600 million tonnes of hydrogen into four million tonnes of energy: the rest is converted into helium 'ash'. Throughout its life the Sun's energy output has continued to increase, and it is thought to have grown 30 per cent brighter in the 4.6 billion years since it formed. Over the next billion years, as more hydrogen is converted to helium, the Sun is set to get about 10 per cent brighter, leading to an increase in heat energy. If we consider the effect that human-made climate change is already having on the weather patterns of our planet, imagine the effect of an increase such as that.

**The remaining planets will drift outwards. Perhaps Earth will make a lucky escape**

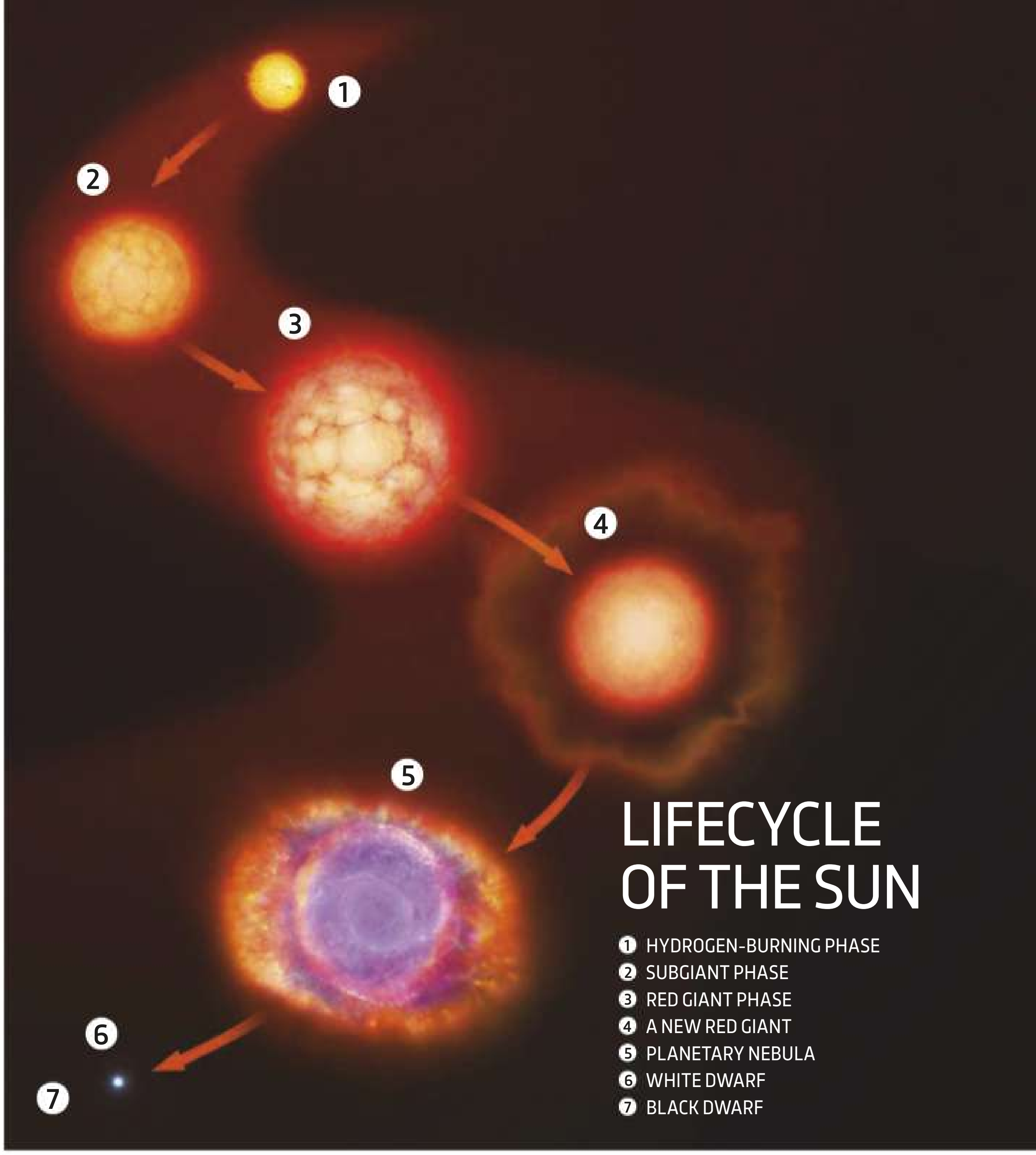
The rising heat will cause the polar ice caps to start to melt and the oceans to warm, sending water vapour into our atmosphere. That water vapour will trap more heat, creating a 'moist greenhouse' effect that will raise global temperatures even higher. About 3.5 billion years from now, the Sun will be 40 per cent brighter than it is today, causing our oceans to boil, the ice caps to melt completely and our atmosphere to be stripped away. Earth will become like Venus: scorched, arid and lifeless.

### 2. SUBGIANT PHASE

As horrific as this scenario is, it is only the beginning of the Sun's demise. About five billion years from now, the Sun will have reached the end of the main sequence of its lifespan, and will have used up all the hydrogen in its core. With no fusion process to counter the force of gravity, the core will begin to contract and become denser over time. As it does so, its temperature will rise and eventually ignite the remaining hydrogen lying outside the core. This new source of fuel will generate enormous amounts of energy that will push the outer layers outwards, causing the Sun to expand two to three times its current diameter, turning it into a subgiant star.

### 3. RED GIANT PHASE

As the surface layers of the Sun are pushed further out, they will continue to trap heat from the dense core buried deep within this ever-expanding shell, and the star will develop into a huge, luminous object called a red giant. These ageing stars can reach sizes between 100 to 1,000 times that of the Sun, and the expanding surface area will cause the temperature of the outer layers to cool to about 3,000°C. The cooler temperature means these stars shine in the redder part of the colour spectrum; hence the name 'red giant'. As the Sun goes through this process it will stretch beyond the orbits of the inner planets Mercury and Venus, completely engulfing them, and may even reach the orbital path of Earth. However, our home planet may not be completely destroyed, as during this expansion the Sun will continue to lose mass: some estimates suggest that at its largest, just 65-70 per cent may be remaining. The gravitational pull will consequently be weakened and the orbits of the remaining planets in the Solar System will begin to drift outwards. Perhaps Earth will make a lucky escape. All the while, the Sun's core will get smaller and hotter, until 12 billion years after




its formation, a new nuclear reaction will occur.

**4. A NEW RED GIANT**

The core will continue to contract until temperatures reach about 100 million °C – hot enough to ignite the helium produced during the consumption of hydrogen and convert it to carbon and oxygen. As the dense core will be unable to expand to allow for this increased energy output, the helium will burn with intense ferocity, producing a brief explosion known as a 'helium flash'. This will lower the density of the core and bring temporary stability, as the helium will now be able to burn at a more controlled rate. However, it won't take long for the new fuel source to be used up; just 100 million years or so. As the helium continues to burn it will generate fierce energy and, just as with the burning of hydrogen, this will cause the Sun to expand once more into a second red giant phase.

**5. PLANETARY NEBULA**

Despite all the expanding and contracting, the loss of mass and the consumption of fuel, the life cycle of the Sun isn't finished just yet. The red giant will continue to convert helium into carbon and oxygen, yet the core will never reach the 600 million °C required to ignite that carbon, so it will begin to contract once more. As the helium is used up, the outer layers will be pushed further out and lost to space so that, about 12.5 billion years after its formation, half of the Sun's mass will remain. The expanding outer layers will be illuminated by the hot core within, creating a glowing cosmic cloud known as a 'planetary nebula'. These phenomena are well known to astronomers and are typical of an ageing star about the mass of our Sun, but have nothing to do with planets. Their name is simply a result of their round, puffed-up shape.

**6. WHITE DWARF**

With the outer layers of the Sun having finally dissipated, all that will remain is a hot, dense core known as a white dwarf. These objects are some of the densest in the Universe, yet are typically just slightly bigger than our own planet. Nevertheless, they can reach temperatures of over 100,000°C. Much of the heat that has been generated in the core throughout the Sun's ageing process is now trapped within this stellar remnant, and it will take tens or even hundreds of billions of years for it to cool.

**7. BLACK DWARF**

The white dwarf remnant will eventually expend all its remaining heat and light energy and (perhaps in hundreds of billions of years) fade into its final stage: that of a lifeless black dwarf. Currently, black dwarfs are merely hypothesised because the Universe, aged at 13.8 billion years, is not yet old enough to have created any, but it is thought that this will be the final fate of our Sun. As if to make the story even more tragic, the low mass of our once mighty star will have lost much of its gravitational pull, causing the planets to drift farther out, nothing more than frozen, charred rocks.

But, as the remnants of our Solar System are lost to space, particles from our own dead Sun could coalesce and begin the process of star formation anew. This may result in the formation of planets with rocky bodies, atmospheres and liquid water primed for new life.

**Iain Todd** is a science journalist and staff writer at *BBC Sky at Night* magazine.


# Mission Discovery Space & STEM Camp

## Team-up with Astronauts & Launch Your Experiment into Space

Students aged 14-18 can meet and work with Astronauts Michael Foale (left) and Tony Antonelli (right) for a week at ISSET's 'Mission Discovery' programme, hosted at King's College London **8th - 12th July 2019** and compete to launch an experiment they design into space to be carried out by astronauts aboard the International Space Station!

> *It was simply brilliant and I will recommend it to many others! I learned so much but it didn't feel like school.*

**- Joanna, Mission Discovery 2018 participant**

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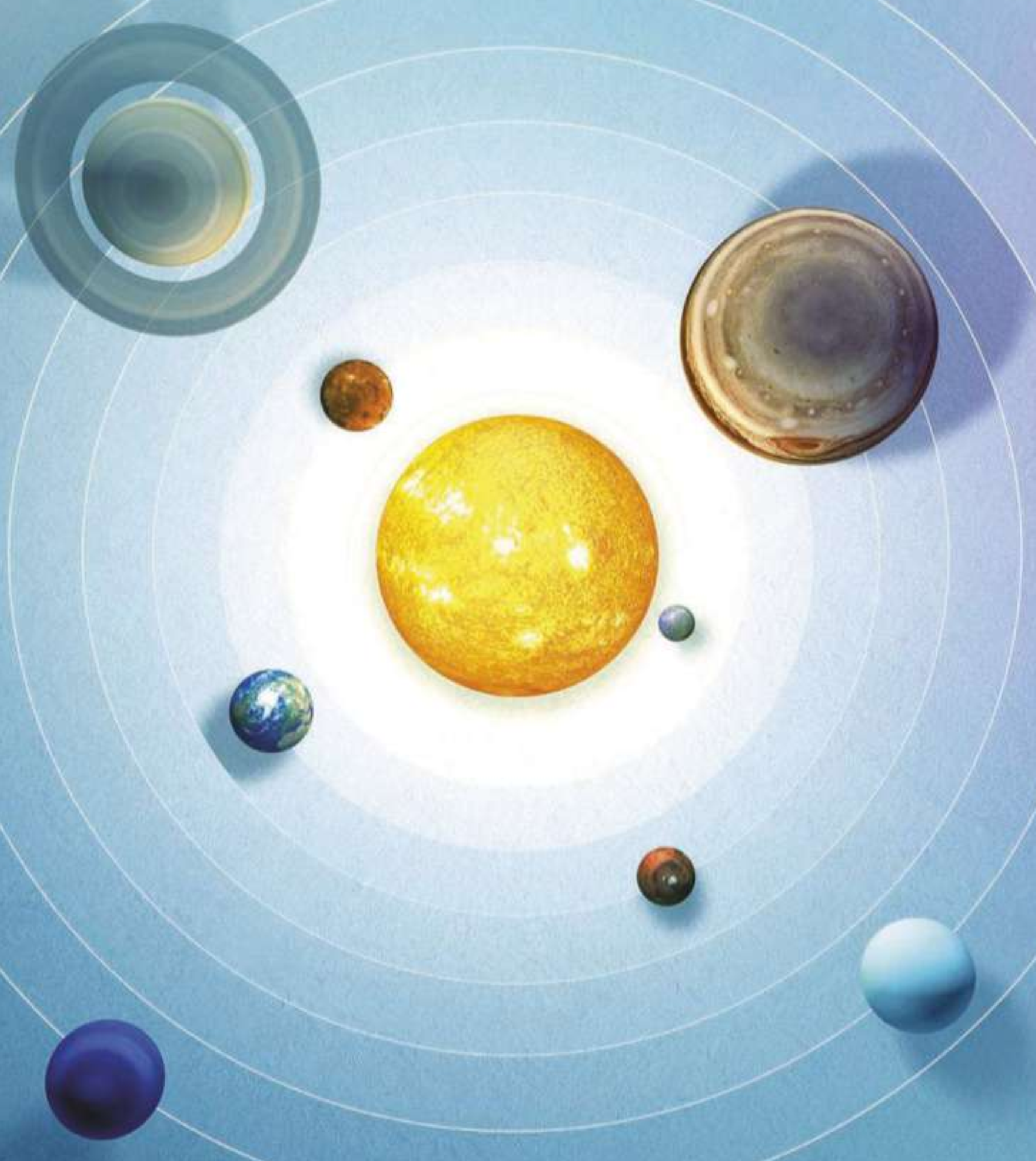

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